Journal

of

THE ROYAL AERONAUTICAL SOCIETY

APRIL 1957

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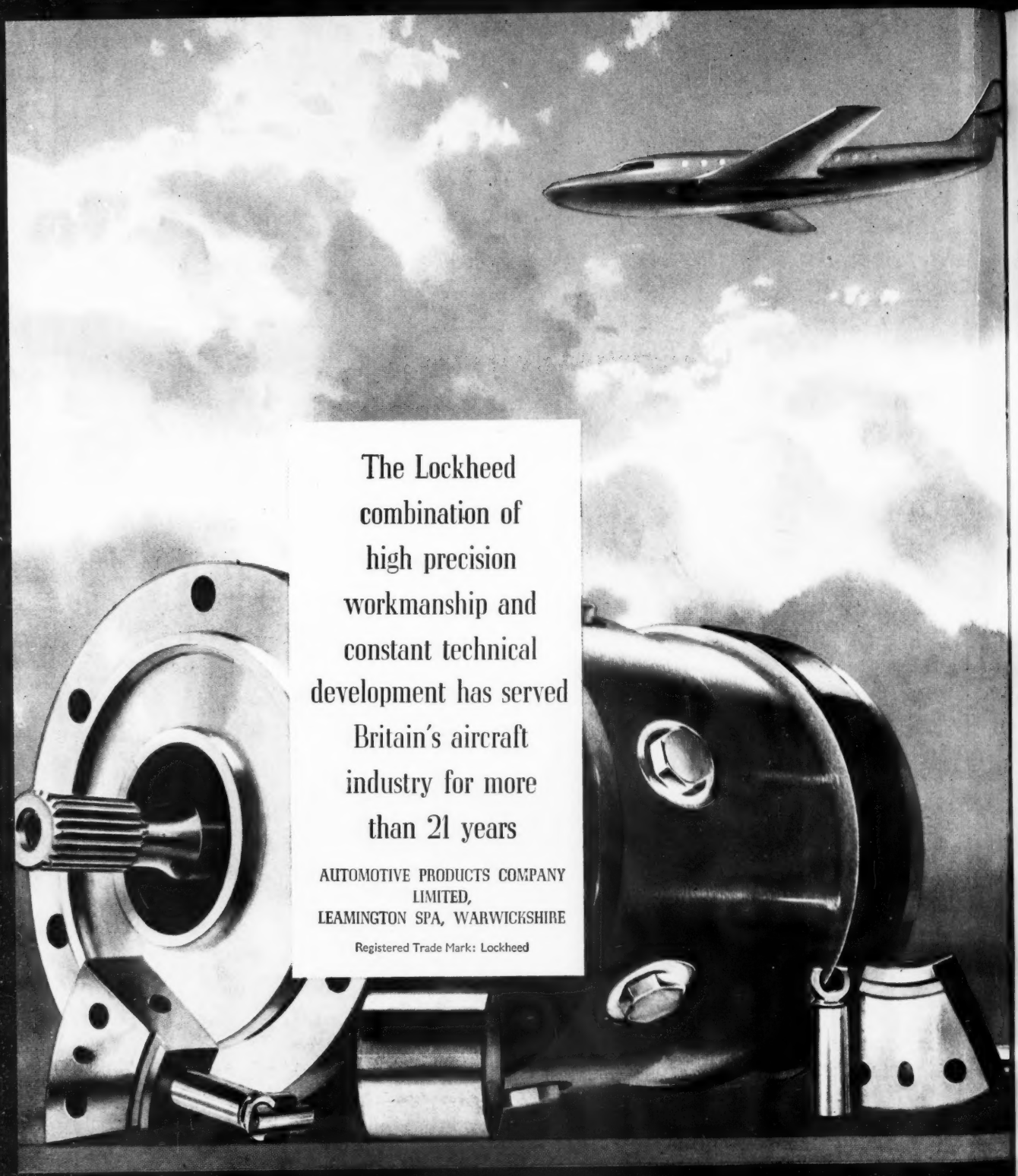

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None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless otherwise stated.

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NOTICES

Easter Holidays

The Library and Offices will be closed from Thursday afternoon 18th April until 9 a.m. on Tuesday 23rd April.

Nomination of Candidates for Council

The following is an extract from the By-Laws: —

"The Twenty-one ordinary members (of the Council) shall be nominated and elected from among the members of the Society. At the date of their election at least ten shall be Fellows, and one at least shall be in each of the following classes: Associate Fellow, Associate and Graduate.

"Of the ordinary members of the Council, that number necessary to create seven vacancies shall retire annually. The retiring members shall be those with the longest service since their last election but they shall be eligible for re-election.

"Nominations of candidates for election to the Council must be received by the Secretary not later than 10th April in each year and shall include statements in writing by the candidates that they are willing to serve. The nomination forms shall be signed by one proposer and two seconders, all of whom shall be Voters."

Nomination forms may be obtained on application to the Secretary.

Annual General Meeting—8th May 1957

NOTICE IS HEREBY GIVEN that the Annual General Meeting of the Royal Aeronautical Society, with which is incorporated the Institution of Aeronautical Engineers, will be held on Wednesday 8th May at 5.30 p.m. in the offices of the Society, 4 Hamilton Place, London, W.1.

AGENDA

1. To read the Notice convening the Meeting.
2. To receive and deliberate upon the Report of the Council on the state of the Society and the Balance Sheet and Income and Expenditure Accounts of the Royal Aeronautical Society and Aeronautical Trusts Limited for the year ended 31st December 1956.
3. To receive the names of those elected to Council for the years 1957-1960.
4. To announce the names of Fellows elected by the Council in accordance with By-Law 4.
5. To elect the Auditors for the year 1957.
6. Any other business.

By Order of the Council

A. M. BALLANTYNE
Secretary.

NOTE: In accordance with the By-Laws any member whose subscription has not been paid before the first day of April is not entitled to vote.

Light refreshments will be served after the meeting.

The British Institution of Radio Engineers

The 1957 Convention will be on Electronics in Automation from 27th June to 1st July at the University of Cambridge. There will be sessions on Office Machinery and Information Processing, Machine Tool Control, Chemical and other Processes, Simulators, Automation in the Electronics Industry, and Automatic Measurement and Inspection. Offers of papers on these subjects are invited and should be addressed to the Institution at 9 Bedford Square, London, W.C.1, accompanied by a synopsis. Further information and forms of application may also be obtained from the General Secretary of the Institution.

The Significance of the Results of Non-Destructive Testing

A symposium, organised jointly by the Royal Aeronautical Society and the Institute of Physics (Non-Destructive Testing Group), will be held on Thursday 30th May 1957 at the Institution of Mechanical Engineers.

The symposium will begin at 10.00 a.m. and continue until about 5.30 p.m. with a lunch break from 1.00 p.m. to 2.30 p.m.

The programme will consist of four contributions by leading experts under the Chairmanship of Professor A. J. Murphy, M.Sc., A.F.R.Ae.S.: —

Crack Propagation in Service, by S. Wise, A.M.I.Mech.E., A.I.M. (Research Dept., British Railways).

Crack Propagation in the Laboratory, by N. E. Frost, B.Sc.(Eng.), A.M.I.Mech.E. (Mechanics and Materials Division, M.E.R.L.).

Critical Assessment of the Non-Destructive Testing Methods used in Aircraft Inspection, by W. Thompson, A.F.R.Ae.S. (A.I.D. Materials Division).

New Problems and Future Trends in Non-Destructive Testing, by W. G. Cook, B.Sc. (Quality Department, Rolls-Royce Ltd.).

Each pair of contributions will be followed by a free discussion period.

It is hoped that, by bringing together physicists with a general background in the field of non-destructive testing and those who apply these methods in engineering practice, a better understanding may be obtained of the results of non-destructive testing and of the extent to which the improvement of the methods employed is necessary or desirable.

The symposium is open both to members of the Society, who should produce their current membership cards, and members of the Institute of Physics who should produce the notice of the meeting.

Others who wish to attend must apply to the Secretary, Royal Aeronautical Society, 4 Hamilton Place, W.1, for a visitor's ticket.

The First Lanchester Memorial Lecture 9th May 1957

The Society has been greatly honoured by Dr. Theodore von Kármán's acceptance of the Council's invitation to read the First Lanchester Memorial Lecture.

The Lecture will be held at the Institution of Mechanical Engineers, Birdcage Walk, London, S.W.1, on 9th May 1957 at 6.0 p.m. Tea will be served at 5.30 p.m. It is hoped that many Members with their guests will take advantage of this opportunity to hear Dr. von Kármán who is so distinguished in many branches of the science of aeronautics.

Wilbur Wright Memorial Lecture 1957 13th September 1957

The Wilbur Wright Memorial Lecture will be delivered this year by Dr. Clark B. Millikan, Director of the Guggenheim Aeronautical Laboratory, California Institute of Technology. His subject will be "Aeronautical Education and Academic Research Policies and Practices in the United States." The Lecture will be held in London on 13th September 1957 and the exact title and venue will be announced later.

"Missiles and Rockets"

If any member has a copy of the first issue of "Missiles and Rockets" which he does not require, the Librarian would be grateful for it to complete the Society's file.

DIARY

LONDON

9th April

SECTION LECTURE.—Fail-Safe Structural Design. N. F. Harpur. Library, 4 Hamilton Place, London, W.1. 7 p.m.

16th April

SECTION LECTURE.—Simulation Techniques in Aeronautics. J. J. Foody and R. A. Paul. Library, 4 Hamilton Place, London, W.1. 7 p.m.

30th April

SECTION LECTURE.—The Purpose and Problems of Research Aircraft. F. P. Youens. Library, 4 Hamilton Place. 7 p.m.

9th May

MAIN LECTURE.—The First Lanchester Memorial Lecture. Dr. T. von Kàrmàn. Institution of Mechanical Engineers, Birdcage Walk, London, S.W.1. 6 p.m. (Tea 5.30 p.m.)

14th May

SECTION LECTURE.—Reinforced Plastics for Primary Aircraft Structures. W. A. Baker. Library, 4 Hamilton Place, London, W.1. 7 p.m.

28th May

SECTION LECTURE.—Flight Instruments. F. W. Meredith. Library, 4 Hamilton Place, London, W.1. 7 p.m.

GRADUATES' AND STUDENTS' SECTION

17th April

PROBLEMS AND PROSPECTS IN AIR TRANSPORT.—P. G. Masefield. Library, 4 Hamilton Place. 7.30 p.m.

15th May

Guided Weapon Research and Development. W. H. Stephens. Library, 4 Hamilton Place. 7.30 p.m.

30th May

Visit to Bristol Aircraft Ltd. *See* Section's page, p. 285.

BRANCHES

10th April

Christchurch.—Annual General Meeting and Film Show. King's Arms Hotel, Christchurch. 7.30 p.m.

Glasgow.—Annual General Meeting. Royal Technical College, Glasgow. 7.15 p.m.

Luton.—Measurement of Aircraft Vibration in Flight. D. A. Drew. Lecture Hall, Luton Public Library. 7 p.m.

11th April

Gloucester and Cheltenham—*at Hereford.*—Application of Nickel Alloys to Aircraft. W. F. Featherstone. 7.30 p.m.

Isle of Wight.—Branch Prize Lectures. Clubhouse, Saunders-Roe Sports and Social Club, Church Path, E. Cowes. 6.30 p.m.

13th April

Bristol.—Visit to Saunders-Roe Ltd., Cowes, Isle of Wight.

16th April

Belfast.—Annual General Meeting. Kensington Hotel, Belfast. 7 p.m.

17th April

Brough.—Annual General Meeting. Lecture Room, The Flying Club, Brough. 5.10 p.m.

Coventry.—Annual General Meeting and Films. The Wine Lodge, The Burges, Coventry. 7.30 p.m.

London Airport.—Transferred from 24th April.—Future Trends in Power Plants. L. F. Snell.

Preston.—Annual General Meeting and Film Show. R.A.F. Association, Preston. 7.30 p.m.

Reading.—Annual General Meeting. Western Manufacturing (Reading) Ltd., Canteen. 6 p.m.

24th April

Gloucester.—Annual General Meeting and Film Show. Wheatstone Hall, Brunswick Road, Gloucester. 7.30 p.m.

Southampton.—Technical Publications. Major H. R. Hockley. Lecture Theatre, Institute of Education, University of Southampton. 7 p.m.

1st May

Chester.—Annual General Meeting. Film Show. Grosvenor Hotel, Chester. 7.30 p.m.

Leicester.—(Transferred from 10th April)—" Pioneers." N. J. Capper. Lecture Theatre, Loughborough College of Technology. 6.30 p.m.

Luton.—Airbreathing Power Plants for Supersonic Flight. A. W. Morley. Lecture Hall, Luton Public Library. 7 p.m.

Weybridge.—Annual General Meeting. Apprentice Training School, Vickers-Armstrongs (Aircraft) Ltd. 6 p.m.

2nd May

Glasgow.—Achievements and Prospects in the Field of Aircraft Engines. Professor A. D. Baxter. Royal Technical College. 7.15 p.m.

JOINT HIGH ALTITUDE AND SATELLITE ROCKETS SYMPOSIUM

This Symposium, organised jointly by the College of Aeronautics, Royal Aeronautical Society and the British Interplanetary Society, and briefly announced last month, will be held at the College of Aeronautics, Cranfield, nr. Bletchley, Bucks, on 18th-20th July 1957.

The Symposium will be devoted to discussions of the problems of designing, constructing and operating high altitude rockets and satellite vehicles, and will be concerned also with their usefulness as tools for scientific research. It is intended, primarily, to bring together people in the rocket and missile field, scientists engaged in high altitude rocket investigations as part of the IGY, and others with similar interests, to discuss future non-military applications and developments of rockets.

The programme of the Symposium will include lectures, prepared and informal discussions, a film show of rocket developments, and an exhibition. The provisional list of lectures includes: (1) Scientific uses of High Altitude Rockets and Artificial Satellites. (2) The Gassiot High Altitude Rocket. (3) High Altitude Rocket Vehicle Design. (4) Propulsion Problems. (5) Guidance, Instrumentation and Telemetry Problems. (6) Problems of Re-entry to the Atmosphere, including Aerodynamics, Heat Transfer and Materials. (7) Future Developments. They will be delivered in two morning and two afternoon sessions on Thursday 18th July and Friday 19th July, and the exhibition will be open on the morning of Saturday 20th July.

An organisation fee of £4 4s. 0d. will be charged to those registering for the whole, or part, of the Symposium. Accommodation and meals will be available at the College for the full period, beginning with dinner on the 17th July and ending with breakfast on the 20th July, at £4 4s. 0d. per head. Those not wishing to stay for the full period will be charged pro rata. Accommodation is limited to a total of 150 persons.

Included in the charges are the supply of preprints of the main lectures and the cost of an informal reception on the evening of 17th July and a Symposium Dinner on 19th July.

Applications for registration and further information should be made to The Warden, College of Aeronautics, Cranfield, Bletchley, Bucks.

INSTITUTE OF THE AERONAUTICAL SCIENCES CALENDAR OF EVENTS 1957

June 17-20	National Summer Meeting, Biltmore Hotel, Los Angeles.
Aug. 6-10	Naval Aviation Meeting, U.S. Grant Hotel, San Diego.
Sept. 1-16	Sixth International Aeronautical Conference, Royal Aeronautical Society and I.A.S., London and Folkestone, England.
Nov. 7-8	Weapons System Management Meeting, Statler-Hilton Hotel, Dallas, Texas.
Nov. 25-26	International Meeting, Canadian Aeronautical Institute and I.A.S., Montreal, Quebec, Canada.
Dec. 17	Wright Brothers Lecture, Department of Commerce Auditorium, Washington, D.C.

A Collector's Piece

Thanks to a Miss Creeth, who is employed at the Ministry of Transport and Civil Aviation, the Society has acquired one of the most valuable relics in its possession. An elderly couple, Mr. and Mrs. Ansell of Bexley, who are neighbours of Miss Creeth, were clearing out some old papers and handed an old ticket for a balloon ascent to Miss Creeth for disposal as she thought fit. Miss Creeth kindly handed it to the Librarian and it turns out to be one for Zambeccari's first ascent at Tottenham Court Road, 23rd March 1785. This ticket is illustrated in Hodgson's "History of Aeronautics in Great Britain" but the illustration bears the stamp of the British Museum. It would seem, therefore, that the Society's specimen is perhaps unique in private collections.

News of Members

H. J. Cohen (*Associate*), formerly with H. M. Hobson Ltd., is now a Plant and Material Handling Engineer with the Northern Electric Co. Ltd., Wire and Cable Division, Canada.

D. C. Dundas (*Associate Fellow*), formerly Site Engineer (Test Beds) with Armstrong Siddeley (Brockworth) Ltd., has now been appointed Works Engineer of that Company.

P. J. Duncton (*Associate Fellow*) has been promoted from Chief Technician to Assistant Chief Engineer (G.W.) with the Fairey Aviation Co. Ltd.

A. G. Elliott (*Fellow*), formerly a Member of Council and a Vice-President of the Society, has been appointed a Member of the Air Safety Board.

J. P. Ford (*Associate*) has been appointed to the Board of Associated British Engineering Ltd. as an Executive Director.

Group Captain E. A. Harrop (*Associate Fellow*), formerly Chief, Aircraft Branch, is now Chief, Maintenance Division of the Logistics Directorate of Headquarters, Allied Air Force, Central Europe at Fontainebleau.

Commander T. G. Horton (*Associate*), formerly Staff Air Electrical Officer to Flag Officer Flying Training at R.N.A.S., Yeovilton, is now Air Electrical Officer in H.M.S. Eagle.

Squadron Leader D. K. Kempston (*Associate Fellow*), formerly employed on Engineering Duties at Royal Air Force, Odiham, has now taken up a technical post on the Staff of Headquarters, Far East Air Force, Changi, Singapore 17.

Wing Commander A. Ovenden (*Associate Fellow*) has taken up an engineering appointment on the Staff of Headquarters, 2nd T.A.F.

Wing Commander L. C. N. Penney (*Associate*) is now with the Engineer Staff of Headquarters Bomber Command, R.A.F. High Wycombe, Bucks. (This notice was incorrectly worded in the March Journal).

J. D. Redding (*Associate Fellow*) has been appointed General Manager of the Sales and Service Department at the Westinghouse Electric Corporation's Aviation Gas Turbine Division.

V. L. Smith (*Associate Fellow*) is now Senior Flight Test Engineer with the Lockheed Aircraft Corporation at Marietta, Georgia, U.S.A.

G. Stevens (*Graduate*), formerly of Short Brothers and Harland Ltd., is now an Experimental Engineer with Saunders-Roe Ltd., East Cowes, Isle of Wight.

N. H. Stewart (*Associate Fellow*) is now a Senior Stressman in the Structures Design Department of Bristol Aircraft Ltd.

C. F. Toms (*Associate Fellow*) is now Chief Project Engineer at Hunting Percival Aircraft Ltd.

W. Wilson (*Associate Fellow*) has left Short Brothers and Harland Ltd. and is now Chief of the Stress Department of the London Office of the de Havilland Aircraft Co. Ltd.

J. B. Young (*Student*) is now a Stress Engineer at Avro Aircraft Ltd., Malton, Canada.

Acknowledgments

The Council wish to acknowledge with grateful thanks the following gifts:—

The late Mr. E. H. Lawford's collection of photographs and postcards of early aeroplanes together with other material of historical interest have been added to the Library through the kind generosity of Mrs. Lawford. Mr. Lawford, who was connected with flying all his life, will be remembered as the pilot of the aeroplane that inaugurated the London-Paris regular daily flights in August 1919.

The manuscript of "The Australian who deserved to fly; being the Life and Work in Aeronautics of Lawrence Hargrave" by Cecil W. Salier has been presented to the Library by the author's daughter, Miss Mary Salier.

Under his will the late A. S. R. Lewin (*Associate*) bequeathed a valuable and interesting album of old postcards and photographs to the Society.

Mr. J. A. Williams, of Laporte Chemicals Ltd., has kindly presented a copy of "Stories of Inventors" by Russell Doubleday, published in 1904

Eleven log books belonging to Mr. W. L. Woodward have been deposited in the Library for safe keeping by the Guild of Air Pilots and Air Navigators.

Eight postcards of the pre-1914 era at Hendon have been presented by the Librarian of the Coulsdon and Purley Public Library, who was asked to forward them to an appreciative authority.

Following a letter from the Society's Librarian which was published in "The Aeroplane" Air Publications on the Siskin IIIA and the Hyderabad and a copy of "Manual du Grade de l'Armée de l'Air" have kindly been presented by Mr. T. F. Sands of Foots Cray, and Mr. W. S. Mitchell of Aylesbury has presented handbooks on the Bristol Bulldog IIA.

As a result of another letter from the Librarian, published in "Engineering," several Ministry of Munitions Publications of the First World War have also been presented.

The Council greatly appreciates the generosity of these donors.

Aluminium in Electrical Engineering

A Symposium on Aluminium in Electrical Engineering has been arranged by the Aluminium Development Association for 16th-17th May 1957 at the Institution of Electrical Engineers, Savoy Place, London, W.C.2. Twelve Papers by electrical engineers with experience in aluminium will be presented in three sessions: General and Economic Considerations in Using Aluminium in Electrical Engineering; Aluminium in Transmission and Distribution Lines; Aluminium in Electrical Equipment.

Applications to attend should be addressed to The Aluminium Development Association, 33 Grosvenor Street, London, W.1.

New Prices for Journal Binding

We regret that because of increased costs in the printing and publishing trade during this past year, prices for the permanent binding of Journals have had to be increased for 1957. The new charges will be:—

Permanent Binding

1956 Volume (including packing and postage) £1 2s. 6d.
Previous Volumes (including packing and postage) .. .. £1 4s. 0d.

Journals, with a note of the name and address of the sender, should be sent direct to The Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the Offices of the Society.

Members are asked to be certain that the address to which they want their Journals sent is the same on their letters to the Lewes Press and to the Society.

Self-Binder Cases

Self-Binder cases of the "Easibind" type to hold 12 Journals (11s. 6d. each) are available from the Society.

Elections

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

Walter James William Arnell (*from Graduate*)
Richard Francis Beresford (*from Graduate*)
Russell John Bickford
Charles George Bourke
Rodney James Thomas Bruce
Richard Gordon Chapman
Amos Henry Chilver (*from Student*)
John Robert Collingbourne (*from Graduate*)
John Albert Conway
Ronald Dickson (*from Graduate*)
William Daniel Disbrey
Alan Donkin (*from Graduate*)
Eric Richard Dudley
Roy William Edwards (*from Graduate*)
Edward R. Geargeoura (*from Graduate*)
Harry Cecil Gedge
John Harold Horlock (*from Graduate*)
Michael Stewart Igglesden (*from Graduate*)
Willard Stone Little, Jr.
Philip George Lockington (*from Graduate*)
James Harvey McClean (*from Student*)
John Blair Macauley
George McGuire
Gilbert McIntosh (*from Graduate*)
Ian Stuart Mant (*from Graduate*)
John Marson
Bryan Rex Noton (*from Graduate*)
Douglas William Pedrick (*from Graduate*)
Richard Alfred Prew (*from Associate*)
Eric Roy Sisson (*from Associate*)
Richard Gordon Slade
Ronald Storey
Ian Charles Taig
Vincent David Trimm (*from Graduate*)
Lionel Peter Twiss
John Bernard Wellingham (*from Graduate*)
Alan James Wheeler (*from Graduate*)
Francis Williams
Maurice Bird Williams
Sinclair Murdoch Wilson (*from Graduate*)
Thomas Gray Young

Associates

John David Bendall
George Victor Blaylock
Eric Ronald Braun
Michael Telfer Cullen
Maurice Albert East
Albert Arthur John Edwards
William Cameron Hannah
Leslie James Hansford
Edgar Glyndwr Aneurin John
John Clifford Knowles
Raymond Cyril Price
Milton Alfred Taylor
Joseph Edward Williams

Graduates

Donald James Bradford
Alan Charles Causon
Khurshid Ahmad Chaudhry
Dudley Albert Clayton (*from Student*)
Clifford John Thomas Coombs
Alec Mervyn Cundick
Eileen Dwyer
Theodore Alexander Ginsburg (*from Student*)
John Desmond Gurney
Robin William Guy (*from Student*)
Derek Vincent Harris
John Morgan Hatfield (*from Student*)
Peter Anthony Jennens
Ngo Duc Lam
Peter Laws (*from Student*)
Derek Anthony Lessware (*from Student*)
Clive Sampson Leyman (*from Student*)
Harry Charles Lowe
Derrick Makepeace
Thomas Markham (*from Student*)
Patrick Christopher Parks
Kenneth Walter Pearce
John Alexander Arbuckle Shaw
Norman Ronald Speddings
George Walters Taylor
David Thomas

Students

David Ivor Allen
Paul William Barker
Brian Henry Brasier
Cedric Herbert Briggs
Frederick John Bundy
Bryan Geoffrey Cox
Thomas William Crowe
Christine Eggleston
Peter William Elwood
Anthony Forrester
Alan Cyril Gardner
Anthony Stapleton George
Rupert Green
Ian Edward Gunn
Robin Thomas Heath
John Heaton
Anthony Edward Herring
Ronald Albert Howell
James John Howlett
Michael John Hyde
Peter Thomas Jenkin
Vijay Kaul
Edward Dennis George Kemp
Ivor Littleton
Andrew Stewart McClymont
Douglas Stewart Macfarlane
Roy McLanaghan
Jatinder Nath Mahajan
Surrinder Kumar Marwaha
Arthur Alexander Mitchell
Richard Campbell Murray
David Oldacre
David John Parcell
Alexander Richard Maurice Pickering
David Frank Pike
John Charles Stuart Prince
David Michael Puddephatt
Geoffrey George Pullum
John William Randall
William Brian Reid
John Oman Ridley
Ernest Ellson Roberts
Michael Frederick Robinson
John Henry Salt
Norman Schofield
Graham Frederic Hugh Singleton
John Robert Stoker
Brian Frederick Tame
Michael Templeman
William Roy Thomas
Alfred Robin Tims
Barry Nigel Tomlinson
Derek John Wheeler
Ernest Wilde
David Williams
Charles Wilson
Francis John Alexander Woodward
Thomas Worden
Ralph Roland Young

Companions

Arthur Harris Ley
Stanley Warren (*from Graduate*)

Income Tax

In response to enquiries from members with regard to a rebate on Income Tax for their subscriptions, the following is a copy of a letter received from the Principal Inspector of Taxes.

Ref: H.R.S.54/C.I. 4420/63.

14th August 1928.

Dear Sir,

Further to your interview with Mr. Stoneley at this office on the 19th July I am now in a position to inform you that the Board of Inland Revenue will not raise objection to the allowance as an expense for Income Tax purposes of annual subscriptions paid by members who are

(*i*) assessable under Schedule D of the Income Tax Acts in respect of professional or trading profits, subject to the decision of the Commissioners who make the assessment that such subscriptions are sufficiently closely related to the business carried on, or

(*ii*) assessable under Schedule E in those cases only in which continued membership of the Society is an essential condition of the terms of appointment.

Yours faithfully,

Signed: GEO. WILCOCK,

Principal Inspector of Taxes.

Secretary,
Royal Aeronautical Society.

Annual Subscriptions

Members are reminded that their annual subscriptions became due on 1st January 1957. The rates are:—

	Home £ s. d.	Abroad £ s. d.
Fellows	5 5 0	4 4 0
Associate Fellows	4 4 0	3 3 0
*Associates	3 3 0	3 3 0
Graduates (aged under 26)	2 2 0	2 2 0
Graduates (aged 26 and over)	2 12 6	2 12 6
Students (aged under 21)	1 1 0	1 1 0
Students (aged 21 and over)	1 11 6	1 11 6
Companions	3 3 0	3 3 0
Founder Members	2 2 0	2 2 0

* Any Associate elected before 1st October 1947 may, if he wishes, elect not to receive the JOURNAL, and in this case his subscription will be reduced by £1 1s. 0d. to £2 2s. 0d.

It will avoid delay and confusion if members, when sending remittances for subscriptions, will state their names clearly and give their addresses and grades of membership. Remittances should be made payable to the Royal Aeronautical Society.

The Journal of the Royal Aeronautical Society

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

VOLUME 61 APRIL 1957 NUMBER 556

HARRY LAWLEY MILNER, *Fellow*

1886 - 1956

WHEN H. L. Milner died suddenly on 19th December 1956 within a few days of his 70th birthday, aviation lost a man whose name commanded respect in any assembly of aeronautical engineers.

Born in 1886, he was educated at Manchester College of Technology and Manchester University; he was a Whitworth Exhibitioner in 1910 and a Whitworth Scholar in 1912, serving an apprenticeship in the shops and drawing office of Sir W. G. Armstrong Whitworth and Co. Ltd. The late Professor Petavel, under whom Milner studied, arranged for an aero-engine to be sent to the University for research work but unforeseen difficulties led to a change of plans and, in 1912, Milner went to the Royal Aircraft Factory where he did research on aero-engines and spent some time in the Aeronautical Inspection Department. After leaving Farnborough he was for five years Managing Director of United Aircraft Co. Ltd. at Gosport and for the next five years a Director of United Manufacturers and Agencies Ltd. in London.

Realising the potentialities of a variable pitch propeller, he joined Dr. Hele-Shaw and Mr. T. E. Beacham, the patentees of the Hele-Shaw-Beacham propeller and undertook the design and development work in conjunction with the Gloster Aircraft Co. Ltd., who held the sole manufacturing licence from the patentees and a development contract from the Air Ministry. Milner joined Glosters in February 1926 and by 1928 a steel-bladed constant speed propeller had been made for the Rolls-Royce Kestrel engine and a duralumin c.s. propeller for the Bristol Jupiter. Both were tested and flown that year and were the first constant-speed propellers to be made, the patent for the Hamilton Hydraulic two-pitch propeller not being applied for until the following year.

As it became evident that engine and propeller design were closely linked, the Air Ministry gave independent development contracts to the Bristol Aeroplane Co. Ltd. and to Rolls-Royce Ltd. In 1934 Milner left Glosters where, in addition to his work on propellers, he had also worked on the Gloster Gauntlet and on various projects, and joined Bristols to continue the development of variable pitch propellers, mainly for the Mercury and Pegasus engines.

In 1937 the Bristol Aeroplane Company and Rolls-Royce formed a new company, Rotol Limited, to pool the results of the work which had been done at Bristol and at Derby on propellers and Milner was appointed Chief Designer. In pre-war days he was responsible for the propellers on the Vickers Wellesleys on their record-breaking distance flight to Australia, and his work of the nineteen-twenties came to full fruition in the Rotol airscrews on the Armstrong Whitworth Whitley and Halifax bombers and on the Hurricane and Spitfire fighters.

H. L. MILNER, *Fellow*.

One of his most important inventions was the Propeller Blade Integration machine. The impossibility of manufacturing blades identically the same led to

vibration trouble, owing to the blades on an airscrew giving different thrusts. The Blade Integration machine summed up the effect of small manufacturing variations in pitch, chord and thickness along the length of each blade and worked out the correction to be applied to the nominal blade setting angle, to nullify the effect of such variations and prevent vibration. This machine was patented in 1941 and before long blades of every manufacture had the correction marked on them before being assembled into a hub for use by the R.A.F. To this day Milner's invention continues to prove its worth.

In later years he was appointed Project Engineer at Rotol and spent his time studying the future trends in propeller and accessory design; evidence of the value of his basic ideas is to be seen on such high efficiency propeller-driven air liners as the Vickers Viscount and the Fokker Friendship.

Mr. Milner became an Associate Fellow of the Society in 1916 and was elected a Fellow in 1944.

Lt. Col. J. D. Blyth, *Fellow*, writes:—

We are for the most part an inarticulate folk, fearful of displaying emotion lest we be thought guilty of sentimentality. Yet there are times when such reticence ought to be overcome and after nearly a third-of-a-century of close friendship, I feel that it is no less than my duty to pay this tribute to the memory of "Pop" Milner, both on my own account and on behalf of all who knew him. The tale of the achievements of Milner the engineer has been told already and, although much might be added to that list, it is Milner the man of whom I would speak now.

By worldly standards his social circle would have been adjudged small, for he neither desired, nor courted, publicity. It would not be strictly true, perhaps, to say that he shunned renown; so modest was he by nature that, in spite of his prowess, I am sure that the idea of such a thing as fame never entered his head.

Kindly and unassuming, he delighted in simple things—the warmth of the sun on his face, the peace of a river bank, pottering in his garden in which (as he told me, chuckling with glee at the story against himself) he once tended a plot with anxious care while he waited in vain for the appearance of a row of beans which he had forgotten to sow! Laughter, indeed, was an essential part of his make-up, quiet bubbling laughter never tinged with spite. He had a sense of humour peculiarly his own—quaint, often impish, always endearing.

Space will not allow me to speak of all the fine traits in his character, but I cannot refrain from quoting a spontaneous compliment to his honesty and integrity contained in a remark made to me some years ago by an engineer with whom I was about to start working. "I don't know much about you," he said, "but you're a friend of 'Pop' Milner's, and that's good enough for me." I felt that I was basking in reflected glory.

The memory of his happy personality will live in our affections; and what more suitable requiem can he have than the words of Kipling, who must surely have had men such as "Pop" Milner in mind when he sang—

> "Let us now praise famous men—
> Men of little showing—
> For their work continueth,
> And their work continueth,
> Broad and deep continueth,
> Greater than their knowing."

London Airport

by

AIR MARSHAL SIR JOHN D'ALBIAC, K.B.E., C.B., D.S.O.

(Airport Commandant, London Airport)*

The one-thousandth-and-fourth Lecture to be given before the Society, "London Airport," by Air Marshal Sir John D'Albiac, K.B.E., C.B., D.S.O., was given on 6th November 1956 at the Institution of Mechanical Engineers, London, S.W.1. Mr. E. T. JONES, C.B., O.B.E., F.R.Ae.S., President of the Society, presided. Introducing the Lecturer, Mr. Jones said that they were to hear from the most competent man in England to give it, a talk on what he would say was the finest airport in the world. He did not think they had had a lecture on a modern airport before and it was worth while reflecting on previous means of transportation. Every previous vehicle of transport before the aeroplane had had to have tracks made for it to take it from one place to another, as well as terminal stations built for it on long distance journeys. Some people commented on the costs of airports, the amount of concrete, etc., but when one realised that the air was provided free of charge and itself provided the means for the aircraft to go from one concrete patch to another, one appreciated that the airport was cheap compared with previous forms of transport. Air Marshal Sir John D'Albiac had, he thought, possibly one of the most interesting jobs in London; he met all the personalities, film stars, and so on. He had been there since 1946 when London Airport was converted from a small airfield. He therefore knew every little bit about it, control, runways, buildings and everything. Sir John started his career in the Army. He found that a little too slow for him and so he transferred to the Royal Naval Air Service. Whether he found that still not quite fast enough he did not know, but he later transferred to the Royal Air Force and he remained in that Service until about 1946 when he retired with the rank of Air Marshal.

Introduction

I AM greatly honoured to have been asked to deliver a main lecture to the Royal Aeronautical Society. It surely must be the ambition of all who are engaged in civil aviation to be granted this privilege, and I feel very proud to be included among those distinguished men and women who have been similarly honoured. I believe this is the first occasion when a main lecture about the London Airport has been given to the Society and perhaps I may be permitted to say that, in view of the pre-eminent position it occupies among other airports of the world, London Airport qualifies in its own right as a very suitable subject.

Obviously it is impossible to cover in detail every aspect of the London Airport. What I propose to do is to summarise broadly the story of the London Airport, its activities and operations, say a word or two as to how it is organised and, finally, refer to some of the more important and pressing problems. I will try not to be too controversial, but with such a rapidly developing subject as aviation there is inevitably much crystal-gazing and many people have different ideas as to what the future holds. Fortunately no one can claim with any justification to know all the answers and this leads to a healthy exchange of ideas. Any comments or opinions I may express are entirely personal ones and not necessarily subscribed to by the Ministry.

As an introduction I would like to give an extract from the author's notes to a novel which was sent to me in the summer and which has as its background the London Airport. To my mind, this extract provides an admirable text to any talk on this subject.

> "The ten years story of London Airport is one of energy and vision, of rapid and continuous progress. Since 1946, when less than 10,000 passengers passed through it each month, it has grown from little more than an open field with a few tents on it to become the magnificently equipped international terminal of today, handling passengers at the rate of two millions a year and with facilities for handling up to seven millions.
>
> "Where the airport is now, a few years ago were market gardens, houses, streams, gravel pits. Suddenly an army came. It moved hills and filled holes, laid great patterns of concrete and built huge structures round them, put down drains and cables and pipes, diverted rivers and razed houses, filled the fields with cranes and bulldozers and trucks and men."

And then the author goes on to describe the airport of today, in these words:—

> "For it is a town. It has faults, still suffers from growing pains, is noisily functional. It is still expanding, still a great experiment, its final shape still dependent upon future aircraft development. But though in many ways like other towns, it is yet like no other. It has its own shops, police force, transport and power services, town council, fire brigade, doctors, warehouses, restaurants, telephone exchange, its own slick language and brittle smell, its own radius of sky more crowded than any in the world. Yet nobody lives there. Its visitors are measured in millions, most of whom stay only a few

*Air Marshal Sir John D'Albiac retired from his post of Commandant, London Airport, in January 1957. He is now Deputy Chairman of the Air Transport Advisory Council.

minutes and then see it no more; they are of every type, nationality and colour. It lives on them but is concerned only to see them go, and the sooner the better."

Original Planning

The London Airport occupies some 3,000 acres of flat and level ground between the Bath Road and the Great South West Road 13 miles due West of London, on a site which originally was occupied by the hamlet of Heathrow. During the Second World War three concrete runways were constructed by the Royal Air Force who intended to use the area as a large transport airfield. At the same time, owing to its obvious advantages, it was planned that, as soon as hostilities ceased, it would be converted to civilian use as the major International Airport for London. With this in view, an Advisory Lay-Out Panel was appointed in 1945 which had as its Terms of Reference: —

> "To consider and make recommendations as to the best layout for an International Civil Airport at Heathrow within a defined area and making maximum use of the three runways being constructed for R.A.F. purposes."

The Report of the Panel, which was dated May 1946, was accepted by the Government of the day, and its plan was put into effect. It is this plan, with one major modification, which has been implemented up to the present time. The plan provided for a total of nine runways—three parallel runways in each of three directions; the three directions to correspond with those of the R.A.F. runways, two of which have been incorporated in the final scheme. The Control Tower and all the passenger accommodation were to be positioned in a diamond shaped area in the centre of the runway pattern, approached from the Bath Road by a tunnel under the northerly East/West runway. Three Maintenance Areas were planned around the perimeter of the airfield—No. 1 to the east for the British Corporations; No. 2 in the south for the foreign operators and independent charter companies, and No. 3 to the south-west for such things as petrol installations, stores depots, and so on.

In their report, the Panel recommended that the airport should be developed in three stages. Stage I consisted of the construction of the first three runways, the associated taxiway and temporary buildings on the Bath Road site. Stage II envisaged the completion of the dual parallel runway system south of the Bath Road, together with some of the central aprons and the main tunnel to the Central Terminal Area. Stage III consisted of constructing the third triangulation of runways to the north of the Bath Road and of developing the facilities in the Central Terminal Area. One of the greatest single difficulties in the whole operation was that all the work had to be so phased as to permit the continuous use of the airport.

In due course, and in the light of experience gained in the operation of aircraft at large airports, it became clear that the third triangle of runways north of the Bath Road would not provide an increase in capacity sufficient to justify the cost. So, in December 1952, much to the relief of the local inhabitants who had been gravely concerned at this possible further loss of their valuable market garden land, the Minister announced that the results of practical experiments showed that the additional amount of traffic which could be accepted by extending the aerodrome north of the Bath Road would not justify the expenditure and disturbance so incurred, and this part of the scheme would be cancelled.

So, except for this modification, the original plan still holds good and is so far being implemented. The position at the present time is that all six runways and the tunnel have been constructed; Nos. 1 and 2 Maintenance Areas, although still being developed, are in occupation, but no progress has yet been made with No. 3 Maintenance Area. Of the permanent buildings in the Central Area, the Control Tower, one passenger building and a third building, which contains airline operating and crew facilities and amenities for the general public, and which is known as "Queen's Building," are constructed and in use. These were all occupied in the Spring of 1955, and we were greatly honoured by a visit from Her Majesty the Queen in December 1955 when she toured the new buildings and officially inaugurated them.

In effect, we have reached what I think can be regarded as the completion of the first phase of our permanent airport, and we are giving a great deal of thought as to our next step. Conditions are constantly changing but our experience leads us to think that so far we are proceeding more or less on the right lines. Whether the completed work will accord entirely with the original plan is perhaps open to question, but the Ministry have taken the opportunity of the completion of the first permanent buildings to make a thorough review of the position, and recommendations will soon go forward to the Minister. There is not a great deal of time as our temporary facilities on the Bath Road site are getting uncomfortably crowded and, with the introduction of larger types of aircraft in the near future, the position may soon become acute. I think we must admit that owing to shortages of money, materials and labour, the completion of the permanent London Airport has taken much longer than was originally hoped. During the whole of this time traffic has increased considerably and we have had to make do with very limited temporary accommodation and facilities. Until a-year-and-a-half ago we dealt with all arrivals and departures in temporary huts on the Bath Road site. Now most of the Continental and all the Internal services are dealt with in permanent buildings in the Central Area. But long-haul services still have to use the Bath Road site. This state of affairs, which is like having two separate airports on the same piece of ground, is perhaps even more complicated now than when we handled all services in the temporary buildings on the Bath Road site, and which I am afraid will have to be the case for at least another three or four years, or more. However, the operators and passengers accept the position in a good spirit and we all look forward to the day when permanent buildings for all will be available in the Central Area. But it was certainly a wise

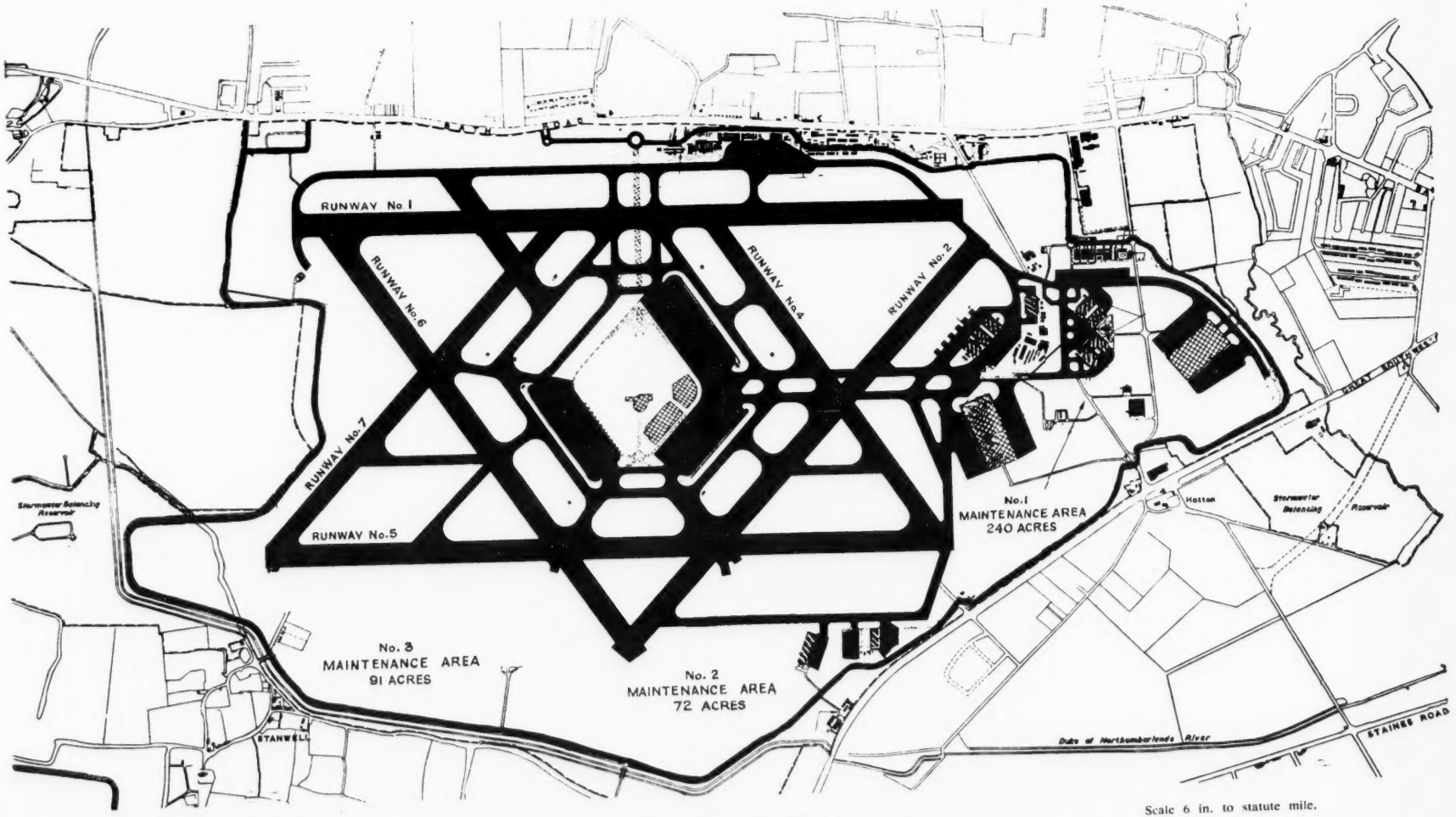

FIGURE 1. London Airport.

move on the part of the Ministry to devote the major portion of our limited resources to perfecting the operational facilities of the airport, even if it did mean a certain amount of discomfort and inconvenience to the airline operators and their passengers while they were on the ground.

Staff Organisation

Like so many other features on the airport, the staff organisation has been developed the hard way—by experience. As is known, the airport is owned by the Ministry of Transport and Civil Aviation. This amalgamated Ministry was brought into effect on 1st October 1953. Before that time we had for a few years a Ministry of our own, which was set up after the war to take over civil aviation from the Air Ministry.

My task as Commandant is to act as the Minister's representative—a sort of resident landlord, and my main purpose in life is to provide facilities which will enable the airline operators, who are our most important tenants, to do their job in the most effective and economical manner. At the same time, it is incumbent upon me to pay the closest attention to our own economics. Airports are extremely costly to construct and run, and although the London Airport can be regarded as a national necessity, we are always looking forward to the day when it will be in a position to support itself financially, and the sooner we can reach that state of affairs the happier we shall be. This subject looms very largely in our minds.

The staff, which numbers about 1,400, and here I had better remind you that they have to work around the clock, 365 days a year—hence the somewhat high figure—is organised on a two-pronged basis—operational and administrative. The operational staff is at present headed by a retired R.A.F. Group Captain who acts as Assistant Commandant. He is responsible to me for all the operational and technical matters on the airport, such as the Air Traffic Control organisation, the inspection and control of all runway and taxiway lighting, the maintenance and operation of all radio and radar aids, and the vast network of telecommunications of all kinds, without which civil aviation could not possibly function. Also under the operational staff is the Aeronautical Information Service at the airport—a sort of A.A. of the air, available to all—and the Airport Fire and Rescue Service, a somewhat unproductive and expensive organisation but nevertheless one which is essential.

The other main branch of the staff deals with the management and administration of the airport. In short, the chores, of which there are many. This branch, headed by what is known as the Airport Manager, is responsible to the Commandant for all buildings, both of permanent and temporary construction, their allocation and letting to tenants and concessionaires, and the maintenance and upkeep of all public rooms. The Airport Manager controls the marshalling aprons around the passenger buildings and the marshalling staffs, the porters within the passenger buildings and those staffs engaged on apron services provided by the Ministry of Transport and Civil Aviation. He is responsible for all non-technical equipment and runs the M.T.C.A. transport section. He runs the finance side of the business and looks after income from rents, concessions and aircraft landing and parking fees. It is also his job to regulate vehicle and pedestrian traffic on the airport and in this he is assisted by the M.T.C.A. Constabulary with a total strength of about 150.

Superimposed on all this more normal routine airport work is the running of the airport public enclosures. When it is realised that on a fine week-end during the summer, anything up to 20,000 visitors to the enclosures, can be expected, it will be appreciated that this is a pretty formidable additional commitment. In addition to the members of the general public who, with their families, come to the airport for an afternoon's entertainment, we also have to deal with a large number of specially arranged conducted tours from schools, public organisations and people connected with civil aviation both from this country and abroad. Apart from the purely secretarial effort in arranging and laying on these visits, the parties have to be met on arrival and conducted around. All this public relations work is an additional load to carry to that of the normal running of the airport, but it is an important and necessary part of the work inasmuch as it helps to publicise the industry and provides a welcomed, although small, addition to the general income.

Relations with Airline Operators

Airline operators, of which there are now 37, headed by the two great Corporations operating regularly at London Airport, are entirely responsible within certain prescribed limits for the conduct of their own operations. In this connection, I would like to tell you a story against myself of an event which happened soon after I took over my appointment, and which made it quite clear to me what my actual responsibilities in this respect were. As a result of an inspection of the runways on a very cold and frosty morning, a day after my arrival, I considered that the braking conditions were far too bad for safety, so I promptly closed the airport for flying and advised all operators accordingly. This action immediately brought down the wrath of all operating company managers, who accused me of grossly exceeding my authority. They pointed out to me, quite rightly, that the responsibility for deciding whether aircraft could land or not was entirely theirs, and that as long as I made all the information available to them and enabled them to make any inspections, should they so desire, that was as far as my responsibility went.

Clearly, operating companies cannot bring in aircraft and despatch them just as they want, irrespective of the wishes of other users of the airport and regardless of the general capacity of the airport, and there has to be some system to deal with the problem. In the first instance, we, the Ministry, lay down a capacity figure expressed in terms of the number of take-offs and landings which can be accepted in one hour. This figure is arrived at by giving consideration to the following three

main factors, any of which can be limiting in themselves while the airport is under construction:—

(*i*) The Air Traffic Control capacity.

(*ii*) The number of aircraft stands available on the aprons.

(*iii*) The capacity of the passenger channels expressed in terms of the number of aircraft loads that can be dealt with in the hour, assuming an average load of 60 passengers.

The Air Traffic Control capacity, in practice, is tied to a great extent to the capacity of the main radio navigational beacons through which all aircraft must enter or leave the London Control Zone in I.F.R. conditions on the one hand, and on the runways by the speed at which aircraft clear the runway after landing, or occupy the runway on take-off. The number of aircraft standings can obviously become the limiting factor in determining capacity and, indeed, may well be so in the very near future, particularly on the Bath Road site. With the opening of the Central Area Passenger Building it is unlikely that availability of passenger channels will be the limiting factor for a few years. Having arrived at a declared capacity, which in practice is reviewed twice annually—once in relation to summer conditions and again in relation to winter conditions, when obviously the I.F.R. element will be more predominant—the capacity expressed in terms of number of take-offs and landings per hour, allowing a marginal increase during peak periods, is handed to the Airport Scheduling Committee. The Airport Scheduling Committee is an airlines committee which appoints its own Chairman and Secretary. Its terms of reference are briefly "to prepare the summer and winter arrival and departure schedules on a basis of joint agreement between all companies making use of the airport, and within the declared capacity of the airport." Obviously, scheduling must be realistic. For example, if departures are bunched together at any one period, take-off delays are inevitable and since, in any case, a declared capacity must be observed, it is in the companies' own interests to space out their movements in order to achieve a smooth flow of traffic. In practice these arrangements work smoothly enough, although we have not, so far, scheduled to full capacity either winter or summer.

Off-schedule movements must be catered for and fitted in with the daily working schedules. If a company based at London Airport, and therefore represented on the Scheduling Committee, wishes to operate extra movements, the company applies to, and obtains, approval from the Secretary of the Scheduling Committee. In the case of operators not based at London Airport, and in respect of all military transport aircraft, application is made to my office in advance. In an emergency, the Air Traffic Control Officer i/c in the Control Tower can accept an aircraft on his own authority.

I am often asked what is the future capacity of the London Airport and when shall we reach saturation? Obviously these are difficult questions to answer as there are many factors involved. As new aircraft equipment, such as flight instruments and I.L.S. couplers, come into more general use and are proved reliable, one can expect more precision on final approach; but we must always allow for the limitations that bad weather will impose, the variations in approach speed and performance of the various types of aircraft and, in the final analysis, the time that any one aircraft will occupy the runway. Simultaneous landings on two parallel runways in I.F.R. conditions are not practicable in the foreseeable future. I should prefer that we should leave it for the present as it stands at 60 movements per hour in V.F.R. conditions, falling to 45 movements per hour in I.F.R. conditions, and rely more on spreading the schedules to avoid bunching at peak periods. There is considerable scope for this at present.

In addition to the meetings of the Scheduling Committee which are attended by a member of the operational staff, regular meetings are held with the operators by both the Operational and Management Chiefs to discuss matters of a routine nature; and in addition I, as Commandant, hold periodic meetings with Operating Company Managers and Heads of Immigration, Customs and Port Health, to discuss matters of higher policy and consider airport problems of major importance. By this means we can keep in touch with operators and their difficulties. I think I can say, with no reservation, that our relations with the airlines are, and always have been, excellent.

Local Authorities and The Press

In addition to our purely domestic committees, the Middlesex County Council, in accordance with the provisions of the Civil Aviation Act, appoints a Consultative Committee which meets every month either at the Airport or the Middlesex Guildhall, to discuss any matters of local interest raised by me or the members of the Committee who, in the main, are representatives of local Councils. This Committee shows great interest in all our affairs and has been particularly helpful over the problem of staff housing which, with a rapidly growing population, has been and still is a burning question. Close contact is also maintained with the local Councils themselves, and lectures and talks are frequently given by me and my staff to Rotary Clubs, Youth Clubs and other similar organisations.

Our work naturally forms the subject of considerable press interest. Apart from a body of resident newspaper correspondents who watch every move, the arrival and departure of any famous, infamous or notorious passenger attracts a large number of visiting press reporters from Fleet Street. Hardly a day passes without the appearance of someone in the public eye and there are few places more attractive to press attention than the London Airport.

On the whole, I think our relations with the press at the airport are good. They have got an important job to do, and I do my best to give them all the help I can to enable them to get what they want. I have, of course, to watch the interests of airline operators and ensure the smooth running of the airport, and at times some of my actions may appear to be somewhat obstructive. But the large majority of the press, particularly the resident

press, appreciate the position and are very co-operative. Here I think I must mention one occasion when I was indeed grateful to them. In April 1955, we brought into use our first permanent passenger building in the Central Area. This was certainly an event in the history of London Airport and the glories of this wonderful building had been much publicised for some time beforehand. As is known, this building contains novel features such as passenger escalators, baggage conveyors, and so on, and with a comparatively untrained staff, conditions for the first few days were pretty hectic. The position was made even more difficult by the presence of hordes of visitors who flooded the building of which they had heard so much. I am afraid there were many cases of passengers losing their way, their baggage and their tempers. What a heaven-sent opportunity for the press to have a really good crack at us and every criticism would have been thoroughly justified and deserved. However, to our great relief, all the London papers went on strike. By the time their dispute was settled, we had sorted out most of the major headaches and the machine was running comparatively smoothly and has been getting better ever since.

Passengers and Freight

So far, I have purposely refrained from giving many statistics, but before leaving the description of the airport I must say something about passengers and freight traffic, and show how steadily it has developed in these past ten years. It will be seen from Fig. 2 how regularly the rate of increase has been maintained. Before the autumn of 1954 the majority of the Continental services coming into the country were handled at Northolt. They then started to operate from London Airport. This accounts for the rather sudden jump in our figures for 1955, but even allowing for this the annual increase has been maintained in a nice steady manner—a good healthy growth.

An interesting feature of these tables, although not very apparent owing to differences of scale, is how the rate of increase in passenger figures is more pronounced than that of aircraft. This is due to two factors—firstly, the gradual introduction of larger aircraft and, secondly, a better loading capacity figure.

There is little to say about the actual passengers except to remark on the wonderful encouragement to civil aviation which is given by members of the Royal Family, and how honoured and proud we are that they use the London Airport so much for going about their arduous business. In looking through my diary a day or two ago, I noted that, so far this year (1956), there have been no less than 78 arrivals or departures of the Royal Family through the airport—a wonderful example to all.

As regards other passengers, it would appear that company executives have come to regard air travel as a necessary and essential part of their business, and with the introduction of tourist services and the gradual reduction in fares, more and more holiday makers are using air travel. Time and motion studies are constantly being made in our passenger channels and we are always

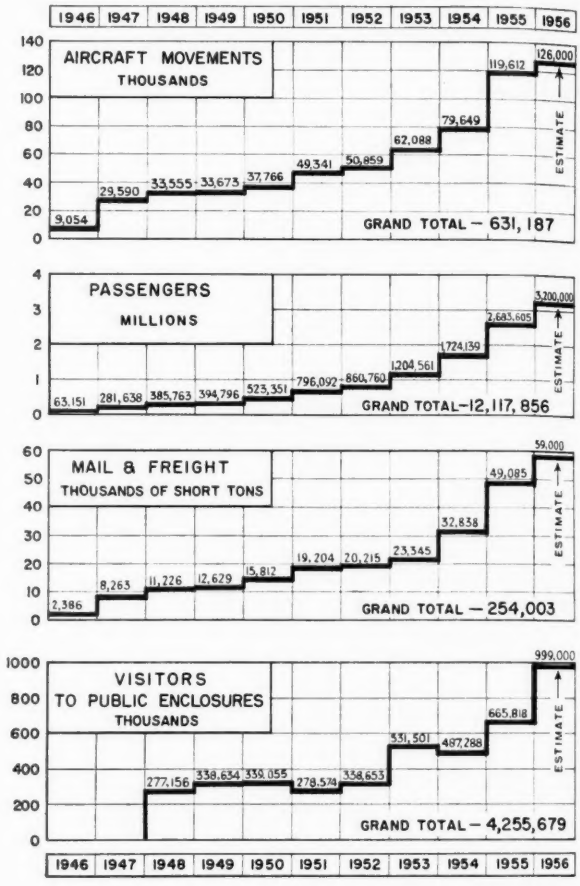

FIGURE 2. Ten years at London Airport. 1946-1956.

striving to reduce as much as possible the time spent by passengers at the airport. The figure we have now achieved compares very favourably, I think, with any other airport in the world.

While on the question of passengers, there is just one point I would like to make. It is not my purpose to criticise the manner in which airline companies conduct their business, and I would not raise this question if it did not affect the actual running of the airport. But for some time I have had a particular "bee in my bonnet" which I feel I must release. It is my firm opinion that, with the possible exception of internal domestic flights, it should be possible to reserve actual seats in all aircraft either at the time of booking or on arrival at the airport. I know that some companies have this arrangement and others provide for seat bookings on all their first-class services, but as the majority of services are tourist, this does not mean much. I also know that after boarding the aircraft, the air hostesses do their best to arrange the seating so that everyone is satisfied. But, to my mind, this is not enough. Only a fortnight ago, I met an oldish couple who had just taken their first flight together. They had enjoyed it a lot, but would have liked it much more if one of them had not been sitting four seats in front of

the other. It might be said that this is purely an airline business and nothing to do with me, but it affects the airport in a curious way. We have gone to a great deal of expense and trouble to furnish and decorate our final lounges in attractive designs and the provision of comfortable chairs and settees. Knowing that the first on to the aircraft has choice of seats, passengers do not use the chairs and relax comfortably, but adopt the national habit of queuing at the doors. As soon as the "starting gun" goes, there is a spirited dash along the airside gallery in which the old and infirm find it difficult to participate. I know that airline staffs will always look after such people if their attention is drawn to them, but this should not be necessary and many people do not like to ask.

At the foot of Fig. 2, I have included figures showing attendances in our public enclosures since we started having enclosures. From this table it will be appreciated what a large business this has grown into in the few years that the London Airport has been open. While we appreciate the interest people show in our work and are delighted to see the figures mounting up in this way, it is unfortunate that the biggest crowds appear at week-ends when all staffs, including my own, like to attend football matches or take their own families out for the day.

I have little to say about freight except to draw attention to the large quantities of livestock that pass through the airport. We now have a very finely equipped hostel provided by the R.S.P.C.A., and I think the following details of animals and birds supplied by them might be of interest. Up to the end of September 1956, from the time the centre was opened in October 1952, no less than 1,614,152 living creatures have passed through their hands. Of this number 269,966 were monkeys destined for the U.S.A. and the Continent for experimental purposes. The remainder have varied from elephants, cattle and racehorses to tropical fish, birds, swarms of bees and boxes of mosquitoes. Apart from the care and attention given to animals at the airport, particularly those in transit, a great deal of research is constantly being carried out by the R.S.P.C.A. in the study of flight conditions, transit conditions and packing problems at the source of origin. I am told that they are actively engaged at the present time in studying high and low frequency sounds as affecting livestock being carried in the new Comet IV.

Some Problems

I would now like to refer to one or two of the more pressing problems which are common to most other large international airports.

The first one is car parking which, of course, is a national problem. Unfortunately, most people connected with civil aviation appear to be either car owners or car users, and a very large amount of available space on the airport has to be set aside for them. Apart from the increasing number of cars belonging to passengers who prefer to come to the airport that way, rather than travel in the airline buses, and I am informed that the figure is between 45 per cent and 50 per cent, there are large numbers of cars belonging to passengers' friends, staff and people coming to the airport on airline business. Superimposed on all this mass transport is the considerable and ever-growing number of cars and buses bringing visitors to the public enclosures. My only real criticism of the design of London Airport is the severe limitation of space that an island site inflicts. It is an interesting reflection on how suddenly and unexpectedly this car parking problem has come upon us, that in the original report of the Lay-Out Panel only the briefest mention is made of car parking requirements. The problem is being actively studied and for the moment we are making use of vacant sites which eventually may be occupied by permanent buildings. A possible solution may be the adoption of silo-type parking garages which take up little space and which, I believe, have been successfully tried out on the Continent.

While on the subject of transport, I must refer to the problem of travelling between the airport and the city centre—a journey which has become progressively slower each year, and which is actively engaging the attention of the Ministry. A number of ideas have been put forward, such as underground railways, overhead railways and helicopter services, but I think the most practical is an extension to the existing surface railway from Whitton, coupled with improvements to the Great West Road. In a recent television broadcast, I asked the member of the staff who was taking part to make an appeal for suggestions to solve this rather difficult problem, and I received a very large number of interesting and useful replies. Some of them were in a somewhat Heath Robinson style, and the one I liked as much as any was that we should dig a canal from the airport to the Thames at Hampton Court and run a service of speed-boats on it.

Another form of passenger transportation which is not very satisfactory—and, with the present shape of aircraft I do not quite see how it can be improved—concerns the journey that passengers have to make to and from the more remote aircraft stands. In the Central Terminal at the London Airport, the passengers are put into 'buses and reach the outer stands through subways under the intervening taxi-track. This all takes time and in wet and inclement weather can be a tiresome, although short, journey. Much thought has been given to conveyor belts and travellators which, I believe, are used in certain places in America, but the cost of installing these rather complicated mechanical systems over long distances may rule out the idea.

In conclusion, I would like to refer to a problem which is an international one and a very serious one, perhaps more so in America than anywhere else. That is, noise.

Unfortunately, it is impossible to run a National Airport without making a great deal of noise and as these airports have, by their very nature, to be near large cities and built-up areas, a great deal of distress and disturbance is caused to the unfortunate people who have to live in the vicinity. A tiresome by-product of this nuisance is the considerable extra work, involving

much time, which is thrown on Commandants and their staffs in dealing with the large number of complaints, telephonic and documentary, which pour in from individuals and Residents Associations. Each case has to be examined carefully and sympathetically dealt with and we try and convince people, often by personal visits and detailed explanations, that we are doing our best to mitigate the nuisance as far as we possibly can; but I am afraid that with all our efforts the situation is more likely to get worse than better as we move into the " jet age." With the full co-operation of the airline operators we restrict the running-up and testing of engines on the ground during night hours to those cases of urgent operational necessity, and plans are in preparation to construct earth baffle walls around the companies' maintenance areas. Also in the siting of new buildings in the maintenance areas, due consideration is given to choosing a site which will shield built-up areas.

But the most difficult aspect of this problem is to deal with the noise made by the take-offs and landings of aircraft in the conduct of the normal operations. We do our best to use runways which lead to the more open country, but at a busy airport any restrictions of this sort are liable to affect the even flow of traffic and can be an additional embarrassment and responsibility to an already heavily worked Control staff and, in my opinion, are not conducive to the efficient running of a national airport. The problem, however, is a serious one and must be faced. A partial solution lies in the hands of aircraft designers and manufacturers who are, I know, fully alive to the problem and are giving it a great deal of study.

PART II—BASIC NOTES

In 1943 the Great West Aerodrome and certain land in the neighbourhood of Heathrow was requisitioned compulsorily, under war powers, to be developed as a large transport airfield for the Royal Air Force, with the possibility of later development as a major civil airport for London. Altogether more than 50 sites were investigated but the meteorological conditions at Heathrow were shown to be as good as anywhere else in the London area, and the site had the additional advantages of a flat and largely unobstructed terrain and gravel sub-soil.

Work on the construction of the airport with a total acreage of 2,709 was started in 1944 but, because of the early end of the Japanese War, it was never brought into use as an R.A.F. airfield and in 1945 was taken over by the Ministry of Civil Aviation.

The first scheduled flight from Heathrow, renamed London Airport, was made on 1st January 1946, although passengers were not carried until June 1946. In 1946 a total of 63,151 passengers passed through the Airport; in 1954 the total was 1,724,139; and in 1955 the figure was about two and three-quarter millions, while the estimate for 1960 is over five millions.

At present the Ministry of Transport and Civil Aviation operates three airports in the London area—London Airport, Blackbushe and Croydon, but over 90 per cent of the passenger traffic in the London area uses London Airport. A fourth airport, Gatwick, which was closed in the Spring of 1956 to allow the necessary development work to be done, is due to reopen in 1958 as London's major alternative.

London Airport, already the busiest in Europe, has six runways arranged in parallel pairs long enough and strong enough to serve any likely transport aircraft and, with the parallel runway systems, a peak flow of sixty aircraft an hour should be possible in reasonable weather.

Plans and Progress

The work which has had to be done on the Airport can be divided broadly into:

(*i*) Site preparation and airfield construction, including diversion of rivers, etc;

(*ii*) the construction of the temporary terminal now known as London Airport North;

(*iii*) the provision of maintenance areas;

(*iv*) the permanent building of London Airport Central.

To begin with, there were no civil buildings, and the first scheduled services were operated from marquees and caravans hastily assembled to provide for passenger reception, customs, immigration and health clearance. By the end of 1946 the single storey buildings originally built for the R.A.F. had been adapted and brought into use and now, greatly added to, comprise the well-known temporary terminal area alongside the Bath Road, which contains the original (now superseded and partially dismantled) control tower, passenger-handling buildings of temporary construction and some of the airline administration offices.

Three maintenance areas were planned around the perimeter; No. 1, the largest, comprising an area of 240 acres east of the runway system, with permanent hangar blocks for the British Overseas Airways and British European Airways Corporations; No. 2, an area of 72 acres south-east of the runway system, for foreign operators and British independent operators; and No. 3, a 91 acre area south-west of the runway system, which has been reserved for future development. The first two maintenance areas are now in use, although they are not completed.

Construction

The actual construction of London Airport is one of the greatest civil engineering projects undertaken in Great Britain in recent years. During the work of preparing the site, two rivers had to be diverted into specially built twin channels round the perimeter of the Airport. The engineering agency responsible was the Air Ministry Works Directorate. The two rivers were the Duke of Northumberland's River, which flows into the Thames near Syon House, and the Longford River, also called the Cardinal's River, since it flows through Hampton Court and is said to have been designed to feed the fountains, and to have been cut, some say by

Wolsey, some by Elizabeth the First of England, and others by Charles the Second, to supply Hampton Court with water.

During the preparation of the Airport, a cannon embedded in the ground at Heathrow, marking the end of General Roy's base line, was removed. (First Ordnance Survey 1784.)

One of the most enterprising features of the Airport construction was the main tunnel from the Bath Road to the site of the new terminal buildings in the centre of the runways. A square reinforced concrete shell was built in the 2,060 ft. long trench and covered over. In this tunnel, which is 86 ft. wide, there are four channels —two dual lane carriageways for motor traffic, and two separate cycle tracks and pedestrian paths. The tunnel is capable of carrying 2,000 vehicles an hour in each direction—about the same number as a main arterial road.

Fluourescent lighting in the tunnel is graded to prevent a sudden change of intensity on entering or leaving the tunnel and fresh air is circulated by fans.

In addition to the runways and the main tunnel, the work at this stage included some subways in the Central Area from the site of the new terminal buildings to the outer aircraft stands; access roads and the provision of drains and stormwater ducts. These stormwater drains, and there are 90 miles of them altogether, lead to stormwater balancing reservoirs in a series of old gravel pits and the water from which is then fed into the Thames. It has been calculated that ¼ in. rainfall over the whole airport is the equivalent of 70,000 tons of water.

All electricity cables are underground—700 miles of them. For the lighting cables alone there are 150 miles of ducts, which would stretch from London to Cardiff. The annual consumption of electricity at the Airport, from 40 sub-stations, is over 35 million units—enough to serve a town of the size of Reigate.

The Central Terminal Area

The Central Terminal Area of 178 acres is connected with the rest of the Airport and the Bath Road by the tunnel. The area reserved for buildings covers 52 acres and is of diamond shape. The present stage of the plan provides for four aprons on the N.E., S.E., N.W. and S.W. faces of the area and four main buildings—the Queen's Building, two Passenger Buildings and the Control Building. Three of the aprons providing 53 aircraft stands on the N.E., S.E. and S.W. faces have been constructed. The stands are arranged in two parallel rows on each side of an inner taxiway passing through the centre of each apron. Construction of the fourth apron on the N.W. face will be undertaken when the need arises. Surrounding the whole area is an outer taxiway system.

The buildings have been designed by Mr. Frederick Gibberd, C.B.E., F.R.I.B.A., M.T.P.I., and approved by the Royal Fine Art Commission.

The Queen's Building (originally called the "Eastern Apex Building") has two main purposes—the handling of aircraft operations, including aircraft and crew clearance, load control, meteorological forecasting, flight planning and crew briefing; and amenities for the general public—a Post Office, News Cinema, Public Restaurant and Buffet, and access to the roof gardens of both the Queen's Building and Passenger Building. The Grill Room has a stepped floor to give a clear view of the airfield and also contains a small dance floor. Private dining room suites adjoin the Grill Room. All the buildings in the Central Area are sealed as much as possible from external noise.

In the Passenger Building (" S.E. Face ") incoming and outgoing passengers go through Customs, Health and Immigration formalities. The passengers arriving by airline bus, or their own transport, are conveyed by escalator to the first floor, where they pass along one of ten passenger-handling channels. These channels run through transverse halls devoted successively to the Concourse, Customs, Immigration, Health and Waiting Rooms. Meanwhile, the passengers' luggage travels on conveyor belts through the ground floor, coming up to the first floor only as it crosses the Customs Hall. In this way a saving of staff is effected and passengers are able to go through the various formalities in comfort and in the minimum time—an obvious advantage, since ground handling is sometimes the limiting factor to the possible number of aircraft movements. Each channel is completely reversible and, since inward and outward traffic peaks seldom coincide, this means that fewer channels are needed and a greater economy is achieved.

Besides overseas passengers, who have to go through these formalities, two other types of passenger have to be catered for—those using internal services for whom two " domestic " channels are provided, and those in transit via London Airport, who do not officially enter the country. Transit passengers have their own self-contained suite on the air side of the Customs barrier, which stretches the whole length of the building. The suite includes buffet-lounge, restaurant, shops, cable offices and a small nursery.

On the second floor of the passenger building there is office accommodation for the operating companies, an extension of the main concourse, with shops, hairdressing salons, a restaurant and a " waving " base for passengers and their friends.

As well as luggage handling, the ground floor provides accommodation for technical staff, supplies and equipment, bonded stores, luggage warehouses and kitchens. The kitchens are used for the preparation of meals served in aircraft, as well as in the restaurants and canteens.

In mid-April 1955, a part of the S.E. Passenger Building, and on 1st December the whole of it, was brought into use for most of the short-haul services. Long-haul and other operations will remain in the present temporary buildings at London Airport North until the second passenger building (now in the preliminary design stage) has been constructed.

The Control Building in the centre, with its control tower 127 ft. 6 in. high, commands an all-round view of the runway approaches and taxiways.

As well as air traffic control rooms, the building contains the headquarters of the airport management, telecommunications, medical centre, restaurant and

welfare facilities for the Central Area staff. The control tower, with complementary technical accommodation in the eastern wing, was brought into use in mid-April 1955 and the building as a whole was completed in August 1955.

The end of the first phase of the provision of permanent buildings was marked on the 16th December 1955, when H.M. The Queen inaugurated these first three permanent buildings.

Approach, Landing and Departure Aids

The tower of the new Control Building is the focal point of a complex system of radio, radar navigational aids, airfield lighting and ground movement control that is the most advanced and comprehensive in the world.

A long-range radar unit operates from a site at the north-west corner of the aerodrome; it can pick up aircraft at distances up to 150 miles from London and its orange and white search aerials can be seen clearly from the Bath Road. Known as M.E.W. (Micro Wave Early Warning) this unit is used by the adjacent Southern Air Traffic Control Centre to expedite civilian air traffic movement by the use of reduced separation standard, to asist civil aircraft with their navigation if called on, and to keep watch on unidentified aircraft.

Aircraft coming to London are routed to Radio Range Stations at either Epsom or Watford, from where they are directed by London Airport Approach Control using radar (A.C.R. Mark VI) so that an orderly sequence of aircraft, spaced at three minute intervals, reach a point about eight miles away on the extended centre line of the particular runway in use for landing. From here the pilot, in bad visibility, may use the Instrument Landing System (I.L.S.) or Ground Controlled Approach (G.C.A.) "Precision", or both, until he can see clearly the runway or its approach lights.

London Airport has two G.C.A. caravans, one in use and one in reserve; both have a duplicated power supply.

The proportion of G.C.A. Landings at the Airport is high, partly because of the uncertainty of British winter weather, but also because only a few aerodromes are equipped with it at present, and even in good weather some airlines ask for G.C.A. to give their crews experience of the system which they cannot get at their home airfields.

Approach Control is responsible for aircraft in the air approaching the Airport, but from just before touch-down to just after take-off they are looked after by the Aerodrome Controller from his office on the roof of the Control Building. At busy airports such as London Airport, these duties are divided into two sections, one for looking after "live" aircraft taking off or landing, and the other controlling taxying aircraft vehicles and pedestrians in the manoeuvring area. The Ground Controller has at his disposal a further radar device, a millimetric system known as the Airport Surface Movement Indicator. This device, which is still in the experimental stage, scans the whole of the runway and taxiway system, and its remarkable accuracy is of great assistance after dark and in conditions of poor visibility. The Runway Controller, in an orange and white van alongside the runway in use, reports visibility and, in emergency, fires Verey Lights as a guide or warning to landing aircraft.

As regards aircraft leaving London Airport, as soon as they are safely airborne the Aerodrome Controller passes control of them over to the Outbound Radar Controller, working on Type II Radar at the Southern A.T.C.C. By using this equipment in conjunction with the M.E.W. already referred to, Controllers are able to monitor the progress of outbound aircraft up to their cruising altitude.

At night, London Airport is identified by two powerful beacons; one, at Heston, flashing alternately white and green, indicating a civil airport nearby, and the other, near the Airport boundary due south from the Central Area, giving the morse letters V.A.—the code signal for London Airport.

The approach lighting system is the best, and also one of the simplest, in the world and was developed by the Air Ministry Works Directorate from a basic design by the Royal Aircraft Establishment. It is known as the Line-and-Bar, or Calvert System and in poor visibility has a centre line of white lights, 3,000 ft. long, with cross-bars of yellow lights at intervals of 500 ft. In poor conditions of marginal visibility the whole system uses red low intensity lights. The last cross-bar of lights which are green, marks the threshold of the runway. From the arrangement of the pattern of lights which the pilot sees he is able to tell whether his aircraft is banked or displaced laterally.

Aircraft taxying at night are guided along the taxiways and runways by following green lights sunk into the centre of the runways and operated from the Control Tower. The runways are divided into "blocks" with controllable "stop" bars of red lights at the end of each block. By day, the route to be followed by taxying aircraft is indicated by lights on numbered boards.

The installation of F.I.D.O. (Fog Dispersal) at London Airport was discussed by the operators, who were asked if they would be prepared to contribute to its cost. The majority were not in favour and preferred to continue with the present arrangements of weather minima and diversion when the weather is too bad at London Airport. A study is, however, still being made of alternative methods of fog dispersal.

Airline Operations

Thirty-seven international airline operators are now using London Airport; in addition, some overseas flights operated by British and foreign charter companies use the Airport frequently.

The first proving flight was flown by British South American Airways (later amalgamated with B.O.A.C.) on 1st January 1946, and in May 1946 the two American companies at that time authorised to operate to the United Kingdom—Pan American World Airways and American Overseas Airlines—transferred their

operations from Hurn to London Airport. Two months later British Overseas Airways transferred its Empire and Atlantic services from Hurn and the first scheduled service of British European Airways from London Airport was flown in April 1950.

Today, passengers are arriving from and departing to almost every country in the world. Here are to be seen airliners of all types, from the older and smaller DC-3's to the big DC-6's and 7's, Stratocruisers and Super Constellations. From London Airport was operated the world's first pure jet airliner—the Comet of B.O.A.C.—and the world's first turbo-prop airliner—the Viscount of B.E.A.C. now used by many other operators as well. Before very long the airliners may be joined by the helicopters; B.E.A. have already operated a daily passenger helicopter service on an experimental basis between London Airport and South Bank.

London Airport is one of the nation's main gateways to the world; on an average day—not during its peak summer or holiday periods—there are some 350 aircraft movements involving well over 10,500 passengers. As far back as 1953 there were three times the number of passengers coming into London Airport and Northolt than were arriving at Dover. As another indication of this growing business, 52 round trips a week were flown in 1949 between London and Paris and by May 1955 the number had increased to 145; in 1949 there were 25 round trips a week between London and New York, and by May 1955 there were 63.

To run this vast undertaking requires a civil aviation working population at London Airport—working in three shifts—of over 22,000; of this number about 1,800 are employed by the Ministry of Transport and Civil Aviation on telecommunications, control and administration.

An important part of London Airport's business is freight, which is handled partly at the eastern end of the Bath Road terminal area and partly in the Central Terminal Area. In 1955, the airlines carried 49,085 (short) tons of freight and mail, and cargoes which have passed through recently have included a six-ton tail shaft for a ship, an eight-ton Linotype printing press, pumps for the floods in Baghdad, 12 tons of foam extinguisher, dresses made in New York, radio-active isotopes, and a collection of a special type of insect being exported for weed-killing, to name but a few.

In fact, the freight-carrying activities of the airline companies make an even more fascinating story than their passenger-carrying operations. The bulk of the lighter air freight is carried on passenger services although some airlines operate special freighters.

To cater for the thousands of animals using London Airport—as many as 47,000 in one month—the R.S.P.C.A. has built an Animal Air Hostel at a cost of about £20,000.

DISCUSSION

B. S. SHENSTONE (Chief Engineer, B.E.A., *Fellow*): Those who worked and almost lived at London Airport liked it very much and they were very glad that Sir John had been there these years to start it going and keep it going, and were sorry that Sir John would not be with them much longer at the Airport.

Now the place where he functioned was at the south-east corner of the airport. From where he sat the impression he got was that the runways were very fine and the buildings most attractive in the Central Area, quite apart from their own buildings, which were attractive in an entirely different way. But he was worried about the future of that Central Area. Sir John had pointed out some of the difficulties, such as cars taking up a lot of space and, as he had said, using areas which should be in the future occupied by buildings. The cars must go somewhere else, but where?

He had also a personal problem. He found very great difficulty in getting from his area to the Central Area because nobody dared cross directly in a motor car or on foot. They had to drive all the way round. He would of course like to see room made for the expansion of the Central Area in this easterly direction so that there would be room for the buildings and the cars and the people, and then of course he would be able to get quite easily into this Central Area and so would others, but he had been told that this was wrong and highly improper because of the runway layout. The most used runways were Nos. 1, 5 and 2, and what he suggested would cut No. 2. But he did feel that something must be done and something drastic. After all, they learned a great deal as time went on and to have to change their minds after ten or fifteen years should be no problem. He merely suggested that they would be forced to cut out runways 6 and 7 and form a peninsular site rooted to the west of the Central Area. It should be organised. Only then would they have room for buildings and cars and be able to develop the subsidiaries and other things that needed to be done in connection with the Central Area. As far as aircraft were concerned, space for stationary aircraft could be expanded, making more room for overnight stops and things like that along the edges of such a peninsula, whereas now they burst their seams in the middle, or were about to do so.

Although he appreciated Sir John's point about the welcome that was extended to visitors on Sundays, if one wanted to get to an aircraft at the Central Area on a summer Sunday afternoon, one found in some cases that it was very difficult to get through the tunnel at all because it was so full of visitors. So his feeling was that the tunnel itself was too small, but he did not suggest building another tunnel. He felt that this expansion in the peninsular form was surely the best way. They might limit the tunnel for the use of passengers and let the other people who used the airport come in through this peninsula. There was nothing but sewage farms to the west to get in the way of the expansion and sewage farms were nothing compared with the difficulties that had been overcome in the past at London Airport.

He knew that it sounded a terrible thing to close

expensive runways, but he thought that runways Nos. 6 and 7 were very seldom used. They would get a far better airport in the future if they were to make these changes. After all, if the cars at present covered the place where two of the three new buildings should be located (and he reckoned they would have twice the number of cars in a few years) the problem was a very dramatic and important one at this very minute. If they extended the Central Area to a peninsular, instead of an insular site, they would then be able to have much more scope in extending the arrangements for aircraft and avoiding what Sir John had called "packaged passengers." If they could have an arrangement where there were fingers which led out direct to the aircraft instead of to a 'bus he was sure it would be far better for the passenger and he would be happier because he would be more independent. The passenger did not like to be pushed about and told where he must go.

SIR JOHN D'ALBIAC: He was in the fortunate position of being able to agree with everything Mr. Shenstone said. There were definite disadvantages in an island site. They all thoroughly appreciated that. It was not too late to alter the original layout if they so wished. They were actively studying the problem now in the light of experience.

However, he did not like doing away with runways on principle. It was perfectly true that some runways were used much more than others but they did get periods when the more normal runways could not be used. If they had no others and were forced to divert aircraft, it could be most inconvenient and unsatisfactory both from the view of the operator and the passengers. He thought that No. 4 runway was rather vulnerable anyhow because they were running short of parking space and it would probably have to be used for this purpose. He was not so happy about doing away with No. 2 because it was such a good runway but he could tell them quite frankly that he was a strong protagonist to do away with this runway as well if they had to remove two runways. But there were many pressing problems to be solved and he could assure them that all alternatives were getting an enormous amount of consideration and study. He thought there were no less than five or six different schemes under review at the present time, all of which had a lot of merit but none of them had no disadvantages, let's put it that way! It was rather a question of deciding which was the best.

P. G. MASEFIELD (General Manager, Bristol Aircraft Ltd., *Fellow*): He thought the President said that this was the first lecture on a commercial airport. But he believed that the first lecture of the Royal Aeronautical Society which he went to was given by that fine person, Nigel Norman about Heston Airport now put out of commission by London, although he thought Sir John still had some people at Heston in various capacities.

At the London Airport they surely had a worthy entry to the United Kingdom. It offered a wonderful first impression of this Country to those arriving and a glamorous memory to those who left. Its runways were as good as anywhere in the World—although the Americans were now busily engaged in making new aeroplanes which might find the runways too short. Might he say that some very large British competitors were not so critical.

There was, he thought, one thing which did need saying and it was this. There was no airport in the World at which the incoming aviator, in whatever capacity, would find greater courtesy and greater kindness from the airport staff—from Sir John down. He had occasion these days to use the airport as a private pilot occasionally and he found himself coming in and out in anything from a helicopter to a sizeable fixed-wing "Giant." The L.A.P. air traffic control people and the controllers were, he believed, the most helpful in the world to talk to over the radio. Nothing was ever too much trouble, whatever the sort of aeroplane, and he would like to pay particular tribute to them, not only from the airline side but also from that of the itinerant aviator who sometimes was an awful nuisance. Whatever one asked of them, they were always courteous whether they gave it to you or not. There was a wonderful G.C.A. team also. That was one of the things which gave one tremendous confidence in coming into London Airport. It was nice to see Mr. Calvert there that evening—because the approach lighting was also better than anything else that he had seen anywhere. His only regret—and Sir John knew this from previous discussions with him in a different capacity—was that there was no FIDO at London Airport. They used to battle for that and even offered to pay for some of it. But there was still no FIDO. He knew that was not Sir John's fault. But one day he hoped that FIDO would be installed, because he believed the new R.A.E. FIDO was going to be very well worth while from an airline point of view.

It had been said that "a chorus of praise has a monotony which is tolerable only in Heaven" and he thought one must not praise everything about L.A.P. As Sir John had disarmingly said, there were a number of shortcomings, and he believed that there were four fundamental errors made in the planning of London Airport, although it was easy to be wise after the event. The central site was quite clearly one error. One could not expand downwards because one got to water. One could not expand sideways because one got to runways. And one could not expand upwards because one got to aeroplanes. It did limit the expansion. That Central Area must evidentially become a peninsula instead of an island. He would much rather see an Eastwards expansion because if people were coming from London, as most did, that would provide the shorter access.

If the island site were the first error—the second was the central taxi-way on the Central apron. He used to battle against it a long time ago because it meant aircraft had to be parked across the apron so that they had to "bus" passengers out to the aircraft. Now that was horrible to have to do. To put passengers into 'buses through one door and then out again and through another door into the aeroplane was one operation too many, and he had always contended that "busing" was the wrong answer. With the island turned into a peninsula, he hoped that "fingers" could be produced so that the 'buses could be done away with.

With the aircraft parked along the fingers the Americans had evolved an excellent system of "first come first served." It stopped the "apron gallop." If one got to the airport early enough the aeroplane was waiting there and one could go and sit in the aeroplanes instead of in a waiting room.

The third point was aircraft parking space. There was not enough room to park aircraft. The "gate and finger" system would help there.

Finally, the architect who designed the building did a marvellous job from the passenger point of view for people who used the airport, for about ten minutes, going and coming. He did not do such a good job for the staff. For those who had to work there, and the lower ranks of the staff in particular, there was "below decks" accommodation, under the floor with no natural lighting and ventilation not very good. Again it was not Sir John's fault of course, but it was a great shortcoming in this airport that the staff quarters where people worked all their lives underground, as it were, had really steerage accommodation. That he thought was wrong.

A matter that had always surprised him about the airport was that the planners rather forgot that aeroplanes needed fuel. There was this wonderful idea of a "petrol farm" on the perimeter. He hoped it would grow a lot. But there was no fuel piped into the Central Area. He believed that he was correct in saying so, that bowsers had to come in periodically through the tunnel—which had to be shut for safety requirements while that was happening. One day he supposed they would have to dig up a runway and put a fuel pipeline into the middle. It was a pity it was not put in first.

He did not want to say these things in any spirit of carping because it was very easy to be wise after the event. He must add, however, that among his personal antipathies were those horrible yellow steps which were wheeled up to the aeroplanes by the airport authorities. An airline name on the steps would be much more aesthetic and Sir John might even be able to charge for it and get a little more revenue. He believed that L.A.P. was the only airport in the World where anonymous yellow steps were used.

The public amenities were of course absolutely wonderful and so were Sir John's viewing arrangements. Indeed, he remembered one occasion on which a passenger was being sought everywhere—he did not speak English—for a service about to leave for Rome. He was found sitting in an airport viewing bus inspecting, he thought, the B.O.A.C. Base when he thought he had been on a bus to get into the aeroplane for Rome! He was having a wonderful time, but the airline was looking for him in every direction. And of course, as Sir John had said, the amenities were not only for passengers. Animals also were cared for in a wonderful way while they were at the airport and he remembered that one airline Public Relations Officer remarked that "every third passenger was a reptile" in his airline. He was not sure he was taken quite the right way!

Of course the city centre to the airport link was vital. Sir John spoke rightly when he said that they had got to look to a rail service into the airport.

He hoped that some of the lessons learned with L.A.P. would be applied to Gatwick, and that the great experience that Sir John had in all these airport directions would not be lost after the 19th January. He trusted that he would be there available as a consultant for Gatwick. Anyway, they all wished Sir John a very happy retirement in the future and hoped that they would continue to see a great deal of him. He had been a wonderful friend to anybody who had occasion to use the airport in any capacity at all.

A. C. CAMPBELL ORDE (Operations Development Director, B.O.A.C., *Fellow*): He would like to add on behalf of B.O.A.C. their very great appreciation of all the kindness and co-operation that his airline had had from Sir John D'Albiac.

He thought that with regard to the future of the airport they in B.O.A.C. went quite closely along with the suggestions which Mr. Shenstone had made and he believed most airlines felt that something in those directions was right.

He would like to add one or two suggestions on the equipment side, having just been looking at these things in B.O.A.C.—he was very conscious of what would be entailed in using much larger aircraft with increased capacity and the services associated with these, and he would suggest that the aircraft industry should make a thorough study of these problems. Today they were all facing more and more integration of design and it was in the systems of the aircraft and servicing facilities that the solutions must lie in making for a more efficient operation. In his opinion they could no longer have mobile equipment on the apron—as they called it here—of the sort even that they had today. The increase in quantity alone made this undesirable; but, taking the power requirements as an instance, it was wrong to have large diesel-engined units running around; and the same really went through the whole operation. He suggested, therefore, that in the design of aircraft they should look much more closely into all these functional problems that arose on the airport itself.

In the case of noise and associated problems of that sort, there were certainly things which could be done to alleviate the difficulties, and he hoped the Aircraft Industry would take advantage of the facilities at London Airport described by Sir John and have a quiet look some time on a busy day in the summer when frequencies were at their height.

SIR JOHN D'ALBIAC: There was just one thing he would like to say about the petrol supply. A plan was actually approved and he thought the money had been alloted for piping the petrol from the farm into balancing tanks into the Central Area.

In conclusion, he would like to say how much he appreciated the nice remarks which had been made about him. Having heard a sample of the sort of people he had had to work with, they would realise what an easy and delightful task his had been for the past ten years.

Wing Section Design for Swept-Back Wings at Transonic Speeds*

by

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1. Introduction

It is well known that the performance at high subsonic and transonic speeds of a swept-back wing-body combination in which the wing is untwisted and has the same section at all stations along the span and in which the body is not specially shaped to allow for the presence of the wing, falls far short of what would be predicted for the corresponding infinite sheared wing. For example, with a sweep of 45° and a thickness/chord ratio of 6 per cent it has been found experimentally that a rapid shock-induced increase in drag occurs above a Mach number of about 0·95 and a peak value of C_D is obtained at Mach numbers slightly in excess of 1·0, whereas it can be estimated that for the corresponding infinite sheared wing, sonic speed in a direction perpendicular to the isobars (the lines joining points where the pressure is equal) would not be obtained until a Mach number of 1·18 was reached. The poorer performance of the finite swept-back wing results principally from the fact that the pressure distributions for sections near the root and tip are distorted in shape from what would be obtained on an infinite sheared wing and, as a result, the isobars tend to lose some or all of their sweep. With a moderate aspect ratio such as 3, such effects extend over most of the span at high subsonic speeds.

Figure 1 illustrates the sort of isobar pattern which is obtained in a typical case. This isobar pattern has been calculated using linearised theory together with certain semi-empirical approximations. The wing has a sweepback of 40° on the quarter chord line, an aspect ratio of 3·5, a taper ratio of 0·4 and a 10 per cent thick, R.A.E. 101 section shape at all stations along the span. With this section, the maximum thickness is at $0{\cdot}31c$ from the leading edge. The calculations are for the wing at zero incidence and at a Mach number of about 0·90 and it is assumed that no shock waves are present in the flow.

In addition to the general tendency for the isobars to be less swept near the root and tip of the wing, as compared with near mid-semi-span, it can also be seen that there is an appreciable spanwise variation in the peak-suction value which is much lower near the root than farther outboard. As a result, some of the isobars do not reach the root and form closed curves and there is a region on the wing surface near the root and ahead of the peak suction line where the isobars are locally relatively unswept.

It is worth while considering the reasons why the isobar patterns tend to have the characteristics just noted. The general formula for the chordwise super velocity component at an arbitrary section of a tapered swept-back wing, is quite complicated even on a basis of linear theory. In its essentials, however, it can be reduced to the form below:—

$$\frac{v_x}{V_0} = \tau k \left[(1 + K_{1\text{root}} + K_{1\text{tip}}) \left(\frac{v_x}{V_0}\right)_{\phi=0} - \right.$$
$$\left. - K_2 \frac{1}{\pi} \log_e \frac{(1+\sin\phi)\,dz}{(1-\sin\phi)\,dx} \right] \cos\phi$$

In this equation,

$$\left(\frac{v_x}{V_0}\right)_{\phi=0}$$

gives the velocity distribution over the section in two-dimensional flow and hence,

$$\left(\frac{v_x}{V_0}\right)_{\phi=0} \cos\phi$$

gives the velocity distribution over this section for an infinite sheared wing. The second term indicates how the velocity distributions are distorted in shape near the root and tip of the wing. At the root, the factor $K_2 = 1$ and at the tip $K_2 = -1$: at the root, the velocities are decreased ahead and increased behind the maximum thickness position, as compared with the values for the sheared wing, while at the tip the opposite effects occur. The magnitude of these effects increases with sweep and hence, for a given wing, increase with Mach number since at high Mach number, the flow around the given wing is effectively related to the incompressible flow around an analogous wing of higher sweep and smaller span. At high subsonic speeds, it has been found experimentally that the distortion effect on the velocity distribution is actually appreciably greater than that given by the second term in the above equation which was based merely on linear theory.

The spanwise decay, with distance away from the root or tip, in this distortion effect, is given by the factor K_2 which is shown plotted in Fig. 2(*a*). This curve has, of course, to be interpreted in terms of the analogous wing and this is why, as in Fig. 1, the isobar sweep at high subsonic speeds still tends to be less than the geometric sweep even near mid-semi-span. The factor K_2 appears to be sensibly independent of both wing sweep and section shape.

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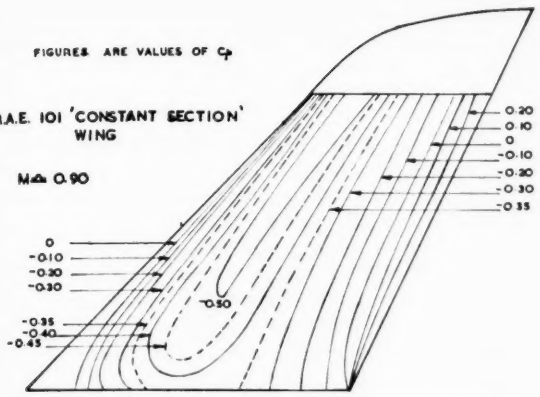

Formula for supervelocity distribution at arbitrary section:

$$\frac{v_x}{V_0} = \tau k\left[(1+K_{1\,\text{root}}+K_{1\,\text{tip}})\right]\left(\frac{v_x}{V_0}\right)_{\phi=0^\circ} - K_2\frac{1}{\pi}\log_e\frac{1+\cos\phi}{1-\cos\phi}\cdot\frac{dz}{dx}\Big]\cos\phi$$

At root	$\tau<1$,	$k=1$,	$K_1=0$,	$K_2=1$
Over mid-semi-span	τ near 1,	$k=1$,	$K_1>0$,	$\lvert K_2\rvert<1$
At tip	$\tau>1$,	$k<1$,	$K_1=0$,	$K_2=-1$

FIGURE 1. Isobar pattern for typical swept-back wing.

The spanwise variation in the peak suction value arises principally from two causes. First, since the wing is tapered, the velocities tend to be reduced near the root and increased further outboard as compared with those for an untapered wing. This is allowed for in the above expression by the factor τ which, for the wing design considered in Fig. 1, varies from about 0·94 at the root to about 1·05 at mid-semi-span and hence, relatively speaking, there is a 10 per cent variation between the two. For a delta wing this effect would be more marked.

The second reason accounting for the spanwise variation in the peak suction value is again associated with the effects of the presence of the kink sections at the root and tip of the wing. In the equation given, it is allowed for by the factor K_1 which, like τ, varies with spanwise position. For the maximum thickness line of an untapered swept-back wing of infinite aspect ratio, the previous equation reduces to:—

$$\frac{v_x}{V_0} = (1+K_1)\left(\frac{v_x}{V_0}\right)_{\phi=0}\cos\phi$$

and so

$$(1+K_1) = \frac{\text{Supervelocity at maximum thickness position of infinite swept wing}}{\text{Supervelocity at maximum thickness position of infinite sheared wing}}$$

At the kink section itself, $K_1=0$ but elsewhere K_1 is greater than 0 or in other words, the velocity at the maximum thickness position at sections away from the kink is increased, due to the presence of the kink. The existence of such a factor can be readily appreciated as follows:—as already seen, the velocities at the root section for points just aft of the maximum thickness are increased by the kink effect; the isobars through these points must, by symmetry, cross the root section at right angles and hence will tend to cross the maximum thickness line a little way out from the root. Hence, an increase in velocity at points out along the maximum thickness line would be expected, but what is important and not obvious at first sight is that this increase becomes a very significant factor at high subsonic and transonic speeds. By calculation, it is found that the magnitude of this increase, *i.e.* of the factor K_1, is very dependent both on the angle of sweep and on the wing section shape. Calculated values are presented in Fig. 2(*b*) for three sections: R.A.E. 101, R.A.E. 104 (with its maximum thickness at 0·42*c*) and the parabolic biconvex section with maximum thickness at 0·5*c*. From Fig. 2(*b*), it can be seen that K_1 is a much more significant factor for the biconvex section than for the R.A.E. 101 section with its farther forward maximum thickness position. However, even taking the smaller values which apply for the R.A.E. 101 section, the maximum value of K_1 obtained at some point along the span increases from about 0·06 for $\phi=40^\circ$ to about 0·26 for $\phi=65^\circ$. One further point should be noted about this K_1-effect. In

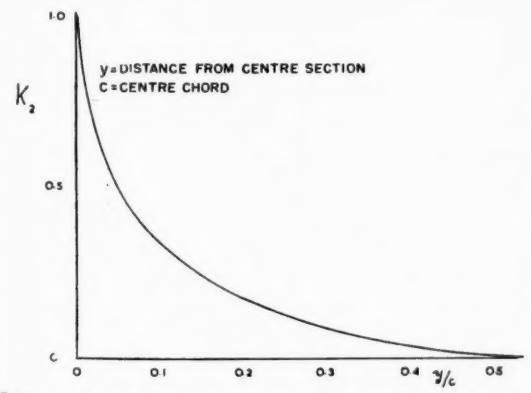

FIGURE 2(*a*). Spanwise decay in distortion effect on velocity distribution.

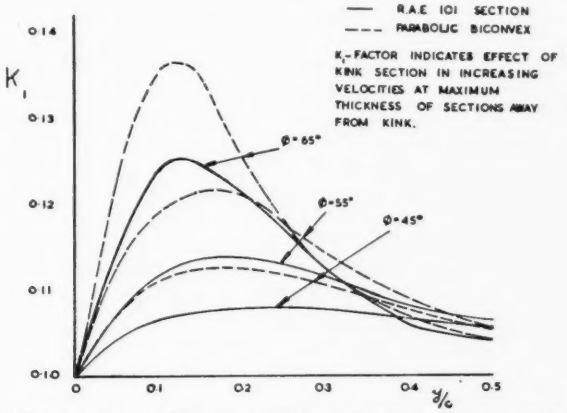

FIGURE 2(*b*). Effect of spanwise position, sweep and wing section on values of factor—K_1.

this respect, the contribution from the root and tip ends of the wing are additive and do not, as with the distortion term, tend to compensate one another. Consequently, for the wing in Fig. 1, the velocities even near mid-semi-span are significantly increased by the combined K_1-effects from root to tip: near mid-semi-span, K_1 is about 0·15: near 0·2 and 0·8 × semi-span, K_1 reaches a maximum of about 0·25 and so, since $K_1 = 0$ at the root, it is clear that this spanwise variation in K_1 is largely responsible for the curving round of the isobars near the root already noted from an examination of Fig. 1.

2. Methods for Improving Subcritical Isobar Patterns

Various methods have been suggested for counteracting the effects just described and so giving an improved performance at transonic speeds. Either the body can be indented opposite the wing in some appropriate manner or the wing section shape can be varied across the span. Particularly since Whitcomb of the N.A.C.A. introduced the now familiar "area rule" concept, most attention has been paid to the idea of shaping the body and indeed it can easily be shown that if the above methods are treated as mere alternatives, shaping the body must be the most powerful single method. However, it is wrong to think of body and wing modifications as mere alternatives: in most cases in practice, best results should be obtained by using both methods, *e.g.* deriving an improved wing design and then shaping the body to suit this. One powerful practical argument in favour of this is that less waisting of the body should then be required. We are concerned here with how the wing sections should be modified and what improvements can be achieved thereby.

It has long been known that, broadly speaking, the modifications to the wing sections should include a forward movement of the maximum thickness position near the root and a rearward movement near the tip. In many cases in practice, a maximum thickness position at the root near 0·12 to 0·15c is needed. Further, the shape of the section at the root should be such that the thickness decreases fairly rapidly immediately aft of the maximum so that whatever the maximum thickness/chord ratio, the thickness aft of, say, 0·5 to 0·6c and the trailing-edge angle should still both be relatively small. The optimum shape may often have an inflection in the surface near the 0·5 to 0·7c. In this way, a forward peak suction position followed by a steady adverse pressure gradient with no second peak suction should result. It is important to realise that these shape requirements aft of the maximum thickness at the root are just as vital as the actual movement of the maximum thickness position itself; the latter, if incorporated by itself with no regard to the former, has been shown to be not necessarily even beneficial.

Similarly, it would appear necessary at first sight to move the maximum thickness at the tip rearward to, say, near 0·6c and to have a small slope over the extreme forward part of the tip section followed possibly by an inflection in the shape. However, the form of the subcritical isobar pattern is only one consideration to be borne in mind when considering what sections should be chosen near the wing tip and the final choice has to be based on a compromise between the different requirements.

If changes such as those just described are incorporated without including in addition any marked spanwise variation in the local thickness/chord ratio, the isobar patterns that would be obtained would still present a far from regular appearance. This is illustrated in Fig. 3. The two wings considered here have the same plan form as before. The wing at the bottom has a 10 per cent thick, R.A.E. 104 section throughout the span, while the wing at the top (Wing *A*) also has this section at mid-semi-span but has different sections at other positions along the span, *e.g.* at the root, the section has its maximum thickness at 0·15c; at about 0·12 of the net semi-span, at 0·35c and then outboard of this, the maximum thickness moves rearward through 0·42c at mid-semi-span to 0·5c at 0·8 × semi-span.

It can be seen that, although many of the isobars of wing *A* are more swept than on the corresponding constant section wing, the other characteristics already noted, namely, the spanwise variation of the peak suction value, is not only not cured on the varying section wing but is in fact much more pronounced. This could have been predicted since if the sections are modified near the root in the way just described, the effective sweep and also the rate of spanwise thickness taper are both

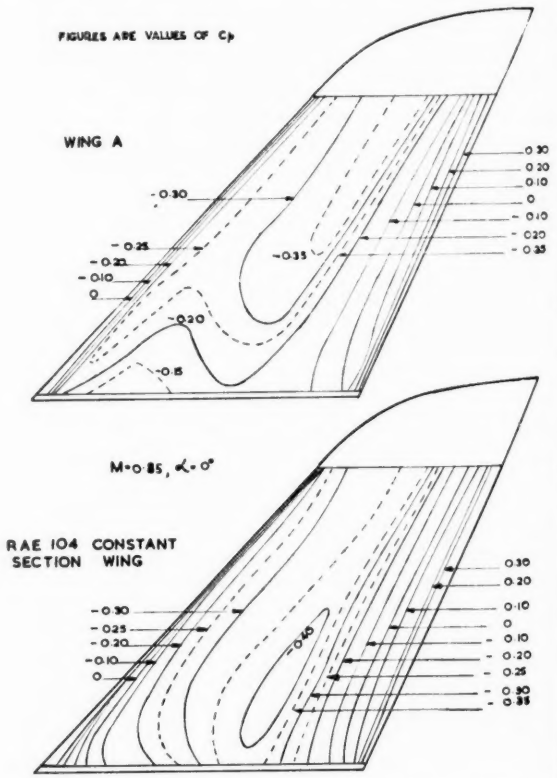

FIGURE 3. Comparison of calculated isobar patterns for "constant" and "varying section" wings.

increased over the forward part of the wing root sections. Both these effects lead to a reduction in the supervelocities at the root and in the present example, this reduction amounts to a halving of the supervelocities at some points.

It follows, therefore, that if this characteristic of some of the isobars curving round and failing to reach the root is to be avoided, it is necessary to include also a spanwise variation in thickness/chord ratio (the rate of variation would have to vary across the span, being greatest close to the root). Since, however, no serious shock wave should form ahead of the main peak suction line, it is not immediately obvious that any ill-effects result from any lack of isobar sweep in this region. This point can only be answered by considering what happens to the isobar patterns at higher Mach numbers after shock waves have formed. The experimental results of wing A were analysed for this purpose. Such an analysis is, of course, needed not merely to settle this one particular point but also to find out in general to what extent conclusions derived from subcritical isobar patterns are valid.

3. Development of Isobar Patterns at Supercritical Speeds on Wing "A" and Conclusions Relating to Wing Section Design

The isobar patterns obtained experimentally for $M=0{\cdot}90$ and $0{\cdot}93$ for wing A are presented in Fig. 4.

The presence and position of a shock wave can be detected from where the isobars are seen to be bunched closely together, *e.g.* near $0{\cdot}7c$ at mid-semi-span. At $M=0{\cdot}90$, the shock wave has just formed over the outer wing and it can be seen to be located well back along the chord where the isobar sweep is relatively low largely because of the geometric effect of the taper of the wing. It seems, therefore, that it would have been better to have chosen a section with a farther forward maximum thickness position for the basic section at mid-semi-span. This conclusion was already known to apply for "constant section" wings: these results suggest that it is also true for wings where the section varies across the span. It is somewhat unexpected but nevertheless true that by spanwise variation of the section shape it is easier to improve on what is already a good constant-section design than it is to improve an initially poor design.

As the Mach number is increased from $0{\cdot}90$ to $0{\cdot}93$, the shock wave near mid-semi-span moves rearward by about $0{\cdot}1c$ but farther out on the wing, it tends to stay in the same place. As a result, the sweep of the shock front over the outer wing is further reduced (to near 22°) and consequently the shock strength increases with Mach number more rapidly than would otherwise have been the case. The absence of any significant rearward movement of the shock over the outer wing appears to be due to the occurrence of a shock-induced separation there with no subsequent reattachment of the boundary layer. This happens above about $M=0{\cdot}91$ for $0{\cdot}8\times$ semi-span and probably earlier than this for sections farther out towards the tip. On the other hand, near or inboard of mid-semi-span, no shock-induced separation has apparently occurred by $M=0{\cdot}93$.

This premature appearance, even at zero incidence, of a shock-induced separation over the outer wing is one consequence of the fact that for this wing at least, the shock strength, particularly at the highest test Mach number of $0{\cdot}93$, increases progressively from root to tip. This can be illustrated in another way. Fig. 5(*a*) indicates the variation with free stream Mach number of $M_{1\max}$ where $M_{1\max}$ is the maximum value of M_1 for some particular section out along the wing and M_1 is the Mach number component perpendicular to the isobars. These values of $M_{1\max}$ should in general be closely similar to the values of M_1 just ahead of the shock and so the variation of $M_{1\max}$ across the span should indicate the spanwise variation of shock strength. Near $M=0{\cdot}87$, there is little spanwise variation but at $M=0{\cdot}93$, $M_{1\max}$ varies from about $1{\cdot}04$ at the root to $1{\cdot}23$ at $0{\cdot}5\times$ semi-span and to $1{\cdot}27$ at $0{\cdot}8\times$ semi-span.

There is some experimental evidence to suggest that this marked spanwise variation in the rate of increase of $M_{1\max}$ with M is a general characteristic that applies to most swept-back wings. For example, with an untapered, 40° swept wing having a 12 per cent thick, R.A.E. 101 section throughout, a Mach number of $1{\cdot}0$ perpendicular to the isobars, (*i.e.*, $M_1=1{\cdot}0$) was reached at $M=0{\cdot}81$ at the root but not until $M=0{\cdot}88$ at a section far from the root. At $M=0{\cdot}93$, however,

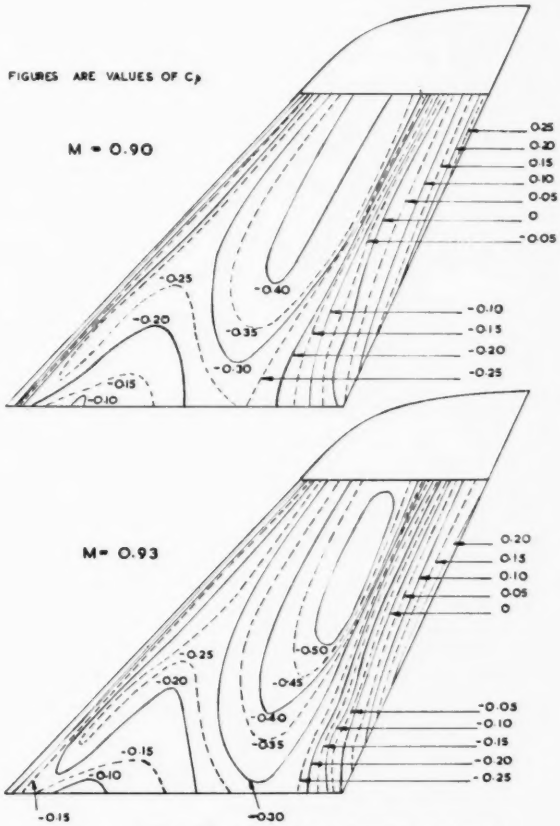

FIGURE 4. Experimental isobar patterns for wing A.

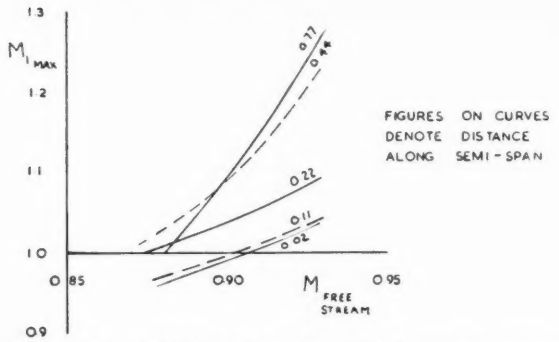

FIGURE 5(*a*). Variation of maximum Mach number perpendicular to isobars with free stream Mach number. Effect of position along span.

$M_1 = 1{\cdot}05$ for both sections thus demonstrating that in this case also, the increase in $M_{1\max}$ with Mach number was much slower near the root than farther out on the wing—at least in this lower transonic range.

It is possible to show that this marked spanwise variation in the rate of increase of $M_{1\max}$ with M is another consequence of the root and tip-kink effects. This can be seen in the following way. In two-dimensional flow, the value of $M_{1\max}$ can be related to the change in slope ($\Delta\theta$) of the aerofoil surface between the forward point x_s, where the velocity first becomes sonic and the point x_m, where $M_{1\max}$ is attained. This relation does not depend greatly on the aerofoil section shape, provided only symmetric sections at zero incidence are considered. The left-hand figure in Fig 5(*b*) shows that doing exactly the same thing for the different sections of the swept-back wing *A* does not produce any correlation between the results for different sections or with the results in two-dimensional flow, but if the variation in isobar sweep between the forward sonic point and the shock front is taken into account by plotting not $M_{1\max}$ but

$$\left[M_{1\max}\frac{\cos\phi_s}{\cos\phi_m}\right]$$

against the change in slope, $\Delta\theta$, the data for the different sections are brought into fairly close agreement. This can be seen in the right-hand figure of Fig. 5(*b*).

It follows that the values of $M_{1\max}$ are principally dependent on three factors, sweep of the shock front, sweep of the isobars over the forward part of the section and finally, the change in surface slope through the region where M_1 is greater than 1·0. The effects of the root and tip can be analysed on this basis and it is found that quantitatively, much the most important factor in the early part of the transonic range is the effect of the root or tip on the rate of forward growth of the supersonic region with increasing Mach number. For example, near the tip, because of the growth of the tip-kink effect with increasing Mach number, the supersonic region extend forward more rapidly than elsewhere and as a result, $M_{1\max}$ increases more rapidly with M. For the present wing at $M = 0{\cdot}93$ and $0{\cdot}8\times$ semi-span, it is estimated that because of this influence of the tip kink-effect, the forward sonic point is at $0{\cdot}18c$ rather than $0{\cdot}30c$ with a consequent increase in $\Delta\theta$ of about 3·5° and in $M_{1\max}$ of about 0·07. Near the root, the opposite applies, *i.e.*, the supersonic region extends forward relatively slowly and the shock strength, therefore, increases only slowly with increasing Mach number. It is quite possible, therefore, that near the root, the shock will have moved back to the trailing edge before it becomes very strong and so the risk of a shock-induced separation occurring there is much less than it is farther out on the wing.

Another conclusion for the above analysis is that one should try and design the wing so that the isobars over the forward part of the inner wing maintain their full sweep and continue into the root. Otherwise, the rate of forward growth with Mach number of the supersonic region near mid-semi-span is accentuated; for wing *A*, for example, it can be estimated that at $M = 0{\cdot}93$, $M_{1\max}$ at mid-semi-span would have only been about 1·12 rather than 1·21 if the isobars over the forward part of the section had maintained their sweep right into the root.

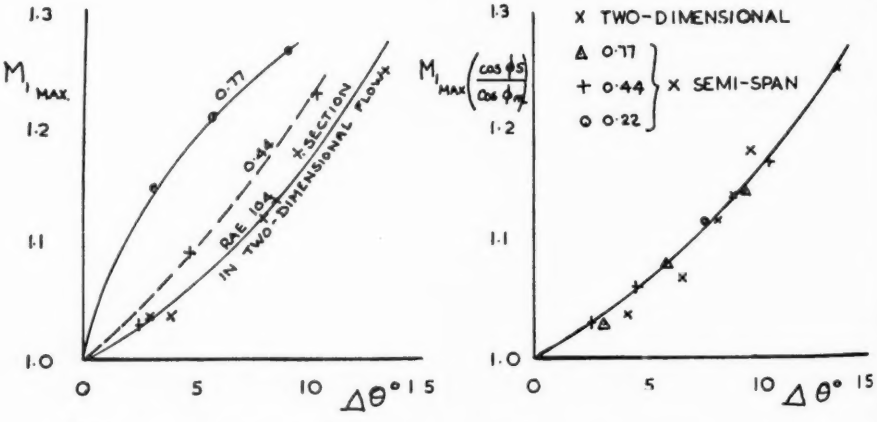

FIGURE 5(*b*). Illustration of how parameter

$$\left\{M_{1\max}\cdot\frac{\cos\phi_s}{\cos\phi_m}\right\}$$

rather than $M_{1\max}$ affords good correlation between results for different stations along span and with two-dimensional results.

The development at supercritical speeds of the flow over the wing near mid-semi-span is, therefore, clearly influenced greatly by what happens both near the root and near the tip. Similarly, the development near the tip is affected by what happens near mid-semi-span and so on. Also, it follows from the preceding discussion that the best design of wing is not the one that attempts to give the same chordwise pressure distribution at all stations across the span at high subcritical speeds. With such a design, it is admittedly true that $M_{1\max}=1{\cdot}0$ would be first attained at about the same free-stream Mach number, whatever station across the span were being considered but as the Mach number was increased further, $M_{1\max}$ and the shock strength would increase most rapidly near the tip. Ultimately, probably, a shock-induced separation would occur near the tip and then this would immediately result in a reduction in the sweep of the shock front inboard of the separation. This increases the shock strength there and hence increases the risk of an inward spread of the separation. In other words, the chain of events, once started, tends to feed upon itself and it is vital, if possible, to prevent it starting. There is therefore, good justification for laying stress and for basing the design on how the flow develops in the initial stages of the transonic range. There is then good hope that improvements in performance may be obtained throughout the transonic range.

It follows that:

(*i*) If possible, the wing sections should be designed on the basis of isobar patterns estimated for a Mach number some way into the supercritical range. In this way, some allowance is made for the continuing increase with Mach number in the root and tip-kink effects. It should be possible to do this because, for a symmetrical section at zero incidence, for Mach numbers up to about 0·05 above the critical, the shock wave does not start to move rearward significantly from the position that would be predicted for it on the basis of calculations made for the supercritical Mach number, using subcritical formulae.

(*ii*) Particular attention is needed to the tip region to try and ensure that a shock-induced separation does not occur there first. In potential flow, this would be achieved by choice of a section shape near the tip with a far rearward maximum thickness position. This implies a large trailing edge angle and is of course just the sort of section shape which, in two-dimensional flow, would be most prone to a boundary layer separation over the rear of the section. This would, of course, still be true and possibly accentuated on the swept wing and hence it would seem that a much safer policy is not to accept literally the section shapes postulated for the outer sections by the results of calculations for potential flow. Instead, a less extreme change in section shape should be incorporated, with a reduction in thickness/chord ratio as compared with the rest of the wing. Such a local reduction in thickness/chord ratio near the tip would have other advantages—for example, the high-incidence characteristics at high subsonic speeds should be improved.

4. Performance of a Wing Designed on the Basis Suggested

A revised wing design *B*, having the same plan form as the previous wings was produced taking account of the conclusions drawn from the analysis of the results on wing *A*. Wing *B* incorporates the following features:—

(*i*) The basic wing section at mid-semi-span is of the R.A.E. 101 shape, *i.e.* its maximum thickness is at $0{\cdot}31c$.

(*ii*) There is a spanwise variation in thickness/chord ratio which varies from 12 per cent at the root to 10·6 per cent to $0{\cdot}115\times$semi-span to 10 per cent at mid-semi-span and 9 per cent at $0{\cdot}8\times$semi-span. It was hoped that the variation near the root would ensure that most of the isobars there would retain their sweep and so reach the wing root. A decrease near the tip is included as suggested already.

(*iii*) The maximum thickness position varies from $0{\cdot}11c$ at the root to $0{\cdot}31c$ at mid-semi-span and to $0{\cdot}5c$ at $0{\cdot}8\times$semi-span. The wing sections were designed as proposed above on the basis of isobar patterns estimated for a slightly supercritical Mach number. The changes in shape are graded across the inner half of the span in a far from linear manner but the full refinement really required near the tip was not included in this design. This was partly because it was felt that analysis of further data was required before the calculation and even the subcritical isobar patterns near the tip could be performed accurately and also partly because on a practical wing, with probably a trailing edge control over

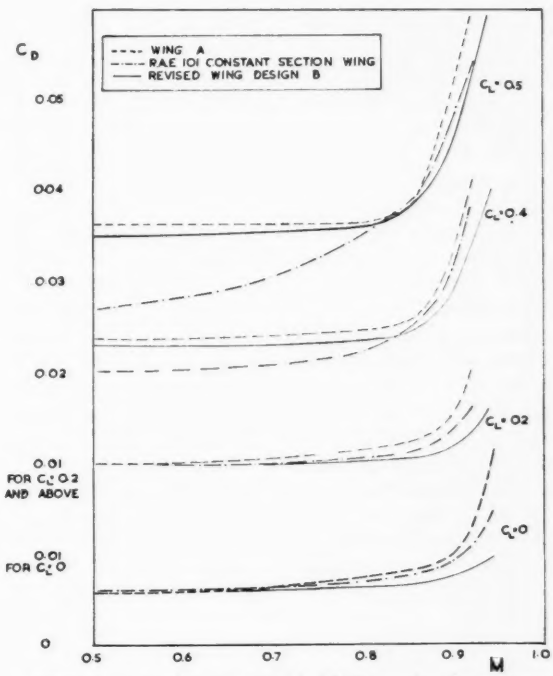

FIGURE 6. Variation of C_D with Mach number improvements from new varying section design.

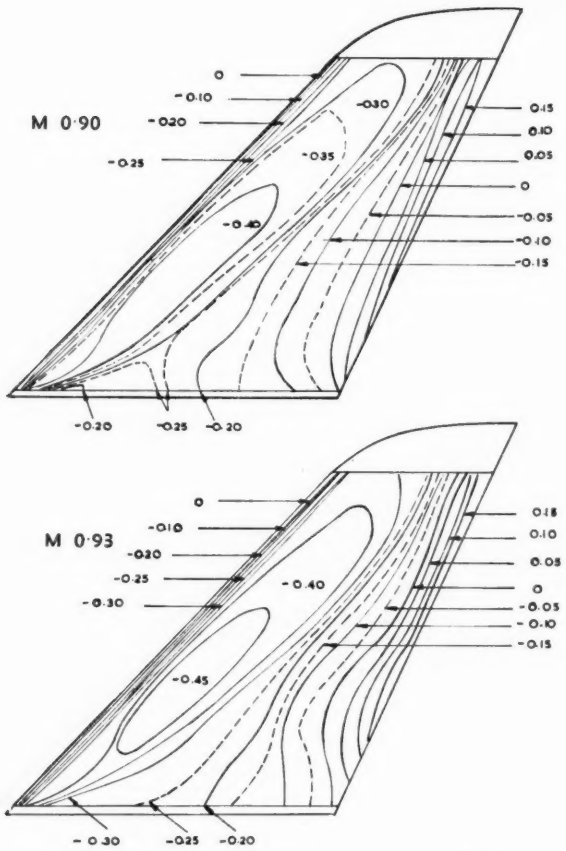

FIGURE 7. Experimental isobar patterns for wing *B*.

the outer wing, sudden discontinuities in surface slope somewhere along this control might not be acceptable.

The drag results obtained for this wing in tests at the R.A.E., Farnborough, are compared with those for the earlier design *A* and for an R.A.E. 101, "constant section" wing of the same plan form and mean thickness/chord ratio in Fig. 6. A large improvement in performance is evident with the new design: at $C_L = 0$, there is apparently no serious shock-induced increase in drag even at $M = 0{\cdot}94$; at $C_L = 0{\cdot}2$, the rapid increase in drag is delayed to Mach numbers more than 0·02 higher than for the constant section wing or 0·04 better than for wing *A*. The rate of drag-rise with Mach number also appears to be somewhat less for the revised wing design *B* and it seems fairly safe to assume that the transonic drag-rise would also be less for this wing. A significant improvement in the Mach number for the increase in drag is still apparent with a revised design at as high a value of C_L as 0·5. It is noteworthy that these gains in performance are achieved despite the fact that on the revised wing, dt/dy varies discontinuously at four stations along the span and there is no attempt to smooth out these changes.

The experimentally determined isobar patterns over wing *B* at zero incidence and at $M = 0{\cdot}90$ and 0·93 are shown in Fig. 7. It can be seen that the isobars are much more swept than for the earlier wing. The shock front when it forms is also more highly swept and analysis of the isobar patterns obtained at higher incidences has confirmed that the shock wave near the tip of wing *B* moves farther rearward than on wing *A* before it becomes of sufficient strength to induce a separation. On the other hand, a striking loss in isobar sweep over the rear of the sections near the root still occurs and an integration of the pressures has shown that the local pressure drag in the immediate vicinity of the root is actually increased with the new wing design (0·08 at $M = 0{\cdot}9$, as compared with 0·06 for wing *A*). In view of the great overall improvement with the new wing, this again confirms that, particularly with wing *A*, much of the shock-induced increase in drag in the lower transonic range comes from sections over the outer wing. In other words, these outer sections are not developing the thrust that is really required to balance the local pressure drag near the root; (one should not conclude from this that modifications near the root are not needed since it is likely that an improved isobar pattern near the root will also automatically tend to lead to an improvement near the tip). To improve the isobar patterns close to the root of wing *B*, it would probably be necessary to include some body waisting and this gives added point to the remark earlier that it is best to think of wing and body modifications not as mere alternatives but as supplementary to one another.

5. Concluding Remarks

There is little or no experimental evidence available regarding the effectiveness of wing modifications such as those described when applied to thinner or more highly swept wings for which the drag rise at Mach numbers less than 1·0 would not be great in any case. However, it is known that the performance of these wings is still very much poorer than would be predicted for an infinite sheared wing and so, in principle, there is no reason why similar improvements should not be possible.

Acknowledgments

The author would like to express his appreciation of the help given to him by members of the Royal Aircraft Establishment, Farnborough, both in carrying out the work described here and for permission to use in this paper various results obtained at the R.A.E.

The Definitions of Quantities Having the Dimensions of Pressure

Although already published by Her Majesty's Stationery Office as A.R.C. Current paper No. 281, this report is considered to be of such general interest that it is published here, at the suggestion of the Aeronautical Research Council, so that it may have a more permanent form of publication and a wider circulation.—Ed.

1. Introduction

In a recent publication[1] the problem of defining the thrust of a jet engine, or the internal drag of a ducted body, is considered in some detail. This Report was compiled by a special Panel of the Aeronautical Research Council and, during its discussions, concern was expressed at the position regarding the definitions of certain quantities having the dimensions of pressure; in some cases the most widely-used definitions were not rigorous, in others a variety of names were in use. In addition, some quantities of considerable value in fluid dynamics were either unnamed or, had been given misleading names. This state of affairs was felt to be undesirable. As a result, the A.R.C. set up a small Panel to consider the matter more fully. The Panel contained representatives from both of the two important groups interested in obtaining uniformity in this field, those concerned with external aerodynamics and those primarily interested in internal flow problems.

The members of the Panel were: —

Professor W. A. Mair (Cambridge University), Chairman.
Mr. I. M. Davidson (N.G.T.E.).
Mr. F. B. Greatrex (S.B.A.C.).
Mr. C. H. E. Warren (R.A.E.).
Professor A. D. Young (Queen Mary College).
Mr. E. W. E. Rogers (N.P.L.), Secretary.

The recommendations agreed by the Panel are given in the following paragraphs; for convenience, the formal definitions of the various quantities are gathered together in an Appendix. The definitions have been framed so that they are applicable to the flow of a continuous fluid; for low-density (*i.e.* free molecular) gases, different definitions would be required.

2. Quantities having the Dimensions of Pressure

The pressure at a point within a fluid can be formally defined as the mean of the normal components of stress on three mutually-perpendicular elements of surfaces at that point, at rest relative to the fluid. For a fluid in motion the pressure is usually called *static pressure* to distinguish it from other quantities also having the dimensions of pressure, and the Panel recommends that the use of this term should continue. The static pressure is the pressure measured by an infinitesimal instrument at rest relative to the fluid, or by a correctly designed and aligned static tube. If the fluid is considered as being composed of discrete molecules, the static pressure can be regarded as arising from the random motion of these molecules, a motion which is superimposed on the general directed motion of the fluid.

If the fluid is brought to rest by a process which is both isentropic and adiabatic*, the pressure increases to a maximum value. The Panel recommends that this maximum value be called the *total pressure* of the fluid. *Reservoir pressure* may be used as an alternative name, where this is more descriptive or is preferred.

In the past, the term "stagnation pressure" has sometimes been used synonymously with total pressure. The Panel recommends that *stagnation pressure* be used only to describe the pressure at a stagnation point on a body, defined, for the purposes of this Report, as a point where the velocity of the fluid is zero relative to the body and where the streamlines divide and continue downstream to follow the contour of the body.

The Panel recommends that the term *dynamic pressure* be used for the difference between the total and static pressures. Bernoulli's equation shows that for an incompressible fluid this is equal to half the product of the density and the square of the velocity, *i.e.* the kinetic energy per unit volume of the fluid. For a compressible fluid this equality is no longer valid and the Panel recommends that the kinetic energy per unit volume should be called the *kinetic pressure*, to distinguish it from the dynamic pressure.

In subsonic flow the total pressure is measured by a Pitot tube if this is correctly aligned, provided that the Reynolds number of the tube is not very small. When the flow is supersonic, however, a normal shock wave exists ahead of the tube and the measured pressure is then the total pressure downstream of the shock wave; this is smaller than the total pressure upstream of the shock wave. The Panel recommends that the pressure measured by a correctly-aligned Pitot tube should be called the *Pitot pressure* for both subsonic and supersonic flows.

The difference between the Pitot and static pressures is commonly used to determine the speed of an aircraft. When the speed is subsonic the quantity measured is the

*It is possible for an irreversible process to maintain constant entropy (*i.e.* to be isentropic) by transferring heat across the boundaries of the flow. In the process being considered this heat transfer must not be allowed to occur; hence the need for the double condition of isentropic and adiabatic flow.

dynamic pressure, but at supersonic speeds the observed pressure difference is smaller than the dynamic pressure. It may be convenient in certain types of work (*e.g.* the determination of position error) to have a name for the difference between the Pitot and static pressures, and the Panel suggest that *indicated dynamic pressure* should then be used.

A quantity which often arises when changes of momentum are being considered is the product of the density and the square of the velocity. This quantity is the momentum flux per unit area across a surface normal to the streamlines and, at present, has no well-established name. The Panel suggests that it should be called the *momentum pressure*; if a need is felt for a more explicit form of this name *momentum-flux pressure* is suggested.

The sum of the static pressure and the momentum pressure arises naturally in applying the momentum equation to determine the force on a body; for this reason the Panel suggests that this quantity be called the *reaction pressure*.

3. Concluding Remarks

It is hoped that a general adoption of the names and definitions contained in this Report will reduce the present ambiguity in the field of fluid dynamics and will encourage uniformity between the various branches of the subject, each of which has hitherto tended to develop its own nomenclature.

APPENDIX

Definitions of Quantities having the Dimensions of Pressure

The following definitions relate to a continuous fluid.

1. *Static pressure.*—The mean of the normal components of stress on three mutually-perpendicular elements of surface, at rest relative to the fluid. It is the pressure measured by an infinitesimal instrument at rest relative to the fluid.

2. *Total pressure.*—The pressure which would arise if the fluid were brought to rest isentropically and adiabatically.

3. *Stagnation pressure.*—The pressure at a stagnation point on a body.

4. *Dynamic pressure.*—The difference between the total pressure and the static pressure.

5. *Indicated dynamic pressure.*—The difference between the Pitot pressure and the static pressure.

6. *Kinetic pressure.*—The kinetic energy per unit volume of the fluid. It is equal to half the product of the fluid density and the square of the velocity.

7. *Pitot pressure.*—The pressure measured by a Pitot tube correctly aligned with the stream. At a point where the flow is subsonic it is equal to the total pressure*; at a point where the flow is supersonic it is equal to the total pressure behind a normal shock wave.

8. *Momentum pressure.*—The momentum flux per unit area across a surface normal to the local flow. It is equal to the product of the fluid density and the square of the velocity.

9. *Reaction pressure.*—The sum of the static pressure and the momentum pressure.

REFERENCE

1. Report of the Definitions Panel on the definitions of the thrust of a jet engine and of the internal drag of a ducted body. C.P., 190, 20th May 1954. *Journal of the Royal Aeronautical Society*, Vol. 59, pp. 517-526, August 1955.

*The exceptional case of very small tube Reynolds number is not considered here.

Solution of Aeroelastic Problems by Means of Influence Coefficients

by

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(Royal Aircraft Establishment)

SUMMARY: It is shown that, on the basis of the data provided by two sets of influence coefficients for a wing (or other surface)—an "elastic" set giving deflections (and hence incidence angles) in terms of applied loads, and an aerodynamic set giving aerodynamic loads in terms of incidence angles (or other linear function of the displacements)—all "static" aeroelastic problems can easily and expeditiously be solved by the use of a digital computer. It is also suggested that the same method of approach may well be used for solving oscillatory aeroelastic problems such as flutter.

1. Introduction

In recent papers[1, 2] the author has described methods for calculating by means of a digital computer the influence coefficients for any kind of wing or other lifting surface. It is axiomatic that, once a comprehensive set of coefficients has been derived for an aeroplane structure, the means is to hand for immediately evaluating the deformation of the structure under every conceivable kind of load. In aeroelastic problems however the complete load is not defined, since part of it is due to air loads engendered by the deformation initiated by the other part.

For the solution of such problems two distinct sets of data are required. The first is a set of "elastic" influence coefficients that gives the deformation of the structure under any given set of loads. The second is a set of aerodynamic influence coefficients that gives, for any stipulated deformation of the structure (including displacements of control surfaces), the set of aerodynamic loads induced by such deformation. Of the two sets it is easier, as perhaps might have been expected, to calculate the first than the second. The fact, however, that there is still some difficulty in expressing the aerodynamic load at each of a set of stations—or pivotal points as they are called by aerodynamicists—in terms of the local incidence angle and the incidences at the other stations, need not deter one from demonstrating the possibilities opened out by the surmounting of that difficulty.

In pursuance of this it will be assumed that aerodynamic theory makes it possible to express the loads at a chosen set of stations in terms of the chordwise incidence angles (or any other convenient displacement parameter) at these stations. The distribution of the stations (or pivotal points) over the wing (or other surface) will naturally be chosen with an eye to making the calculation of the loads as easy as possible, and they will therefore in general be quite distinct from the set of stations used in calculating the elastic influence coefficients.

The purpose of this report is to show how straightforward many aeroelastic problems become once the elastic and aerodynamic characteristics of the structure have been expressed in terms of the corresponding influence coefficients. For this, of course, a digital computer is a *sine qua non* both in the evaluation of the coefficients and in the subsequent aeroelastic calculations.

Received 30th August 1956.

NOTATION

A	"aerodynamic" station
"a," "b," "c," "d"	"elastic" stations
b, c, d, e, g, h, k	coefficients
I	unit matrix
l	defined in Fig. 1
l_c	(in Section 4.3) convenient datum spanwise distance from plane of symmetry
L	distance from tail datum point to c.g. of aircraft
p	rolling velocity
q	pitching velocity
Q	general load
P	function of Q
R	particular aerodynamic load (*see* Section 3)
V	flight speed
w	deflection
α	angle of incidence
β	aileron angle
α_E	change in incidence due to elastic deformation
α_e	direct incidence change due to elevator angle
α_β	wing incidence due to aileron angle (variable with spanwise direction)
α_p	wing incidence due to roll, as a fraction of that at section l_c
α_q	indirect incidence change due to pitching velocity q, expressed as a fraction of that at datum point

Suffices

a, b, c, d	"elastic" stations
T	tail

2. Elastic Influence Coefficients Appropriate to Aerodynamic Stations

For the purpose of deriving the elastic influence coefficients of a wing, the stations are usually distributed over the wing surface so as to lie along equally spaced chordwise and spanwise lines, thus forming a chessboard pattern with a station at the corner of each square. The distribution of the aerodynamic stations, on the other hand, will tend to become progressively denser from root to tip. A first task therefore is to derive from the original elastic influence coefficients a new set applicable to the aerodynamic stations.

This is easily accomplished, since every "aerodynamic" station must be situated inside one or other of the chessboard squares formed by the original "elastic" stations. Thus, in Fig. 1, A represents an "aerodynamic" station surrounded by the four "elastic" stations "a," "b," "c" and "d." Any aerodynamic load Q_A can be apportioned between the four stations as P_a, P_b, P_c and P_d. The fact that considerations of equilibrium cannot alone govern this division of load is of little moment, since any reasonable division (based on a standard convention) is good enough, having regard to the fact that the square mesh is small in comparison with the total wing area.

Referring to Fig. 1 we may, for example, well write

$$\left.\begin{aligned} P_a &= Q_A(l-l_1)(l-l_2)/l^2, & P_b &= Q_A l_2(l-l_1)/l^2 \\ P_c &= Q_A(l_1 l_2)/l^2, & P_d &= Q_A l_1(l-l_2)/l^2 \end{aligned}\right\} \quad (1)$$

It might be thought at first glance that, because the aerodynamic load is essentially a distributed load, it should be spread over a greater number of "elastic" stations than the four stations immediately surrounding it. This would be a more valid objection if stress evaluation had been the aim. The fact that, in aeroelastic problems, it is the deflection of the structure that is alone of importance, allows a locally distributed load to be perfectly well represented by an equal load concentrated at its "centre of gravity."

Any set of loads $Q_1, Q_2, \ldots Q_r$ at the r "aerodynamic" stations can thus be represented by n loads P at the "elastic" stations, each load P being a function of the Q's as just explained. Assuming now that the n^2 influence coefficients relating to the n elastic stations are known, the deflections w can be written as follows:

$$\left.\begin{aligned} w_1 &= b_{11}P_1 + b_{12}P_2 + \ldots + b_{1n}P_n \\ w_2 &= b_{21}P_1 + b_{22}P_2 + \ldots + b_{2n}P_n \\ &\cdots\cdots\cdots\cdots \\ w_n &= b_{n1}P_1 + b_{n2}P_2 + \ldots + b_{nn}P_n \end{aligned}\right\} \quad (2)$$

Since the local incidence angle at any aerodynamic station such as A of Fig. 1 can at once be written down in terms of the deflections of the four surrounding stations "a", "b", "c", and "d" equation (2) enables us to express the r incidences in terms of the n P's. Thus the incidence α_A at A is written as

$$\left.\begin{aligned} \alpha_A &= \alpha_{ad} + (l_2/l)(\alpha_{bc} - \alpha_{ad}) \\ &= (w_d - w_a)/l + (l_2/l)\{(w_c - w_b)/l - (w_d - w_a)/l\} \\ &- \frac{1}{l}\left[\left(1 - \frac{l_2}{l}\right)(w_d - w_a) + \frac{l_2}{l}(w_c - w_b)\right] \end{aligned}\right\} \quad (3)$$

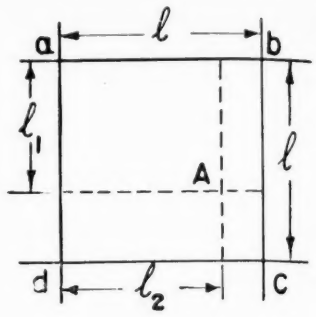

FIGURE 1.

the right hand side of which, by virtue of (2), can be expressed in terms of the n P's. The r local incidences at the r aerodynamic stations 1′, 2′ . . . r' may thus be written as

$$\left.\begin{aligned} \alpha_1' &= c_{11}P_1 + c_{12}P_2 + \ldots + c_{1n}P_n \\ \alpha_2' &= c_{21}P_1 + c_{22}P_2 + \ldots + c_{2n}P_n \\ &\cdots\cdots\cdots\cdots \\ \alpha_r' &= c_{r1}P_1 + c_{r2}P_2 + \ldots + c_{rn}P_n \end{aligned}\right\} \quad (3a)$$

where the coefficients c are linear combinations of the coefficients b of (2).

By means of equations such as (1), the P's on the right hand side of (3a) can be expressed in terms of the Q loads at the aerodynamic stations, so that (3a) can finally be written

$$\left.\begin{aligned} \alpha_1 &= d_{11}Q_1 + d_{12}Q_2 + \ldots + d_{1r}Q_r \\ \alpha_2 &= d_{21}Q_1 + d_{22}Q_2 + \ldots + d_{2r}Q_r \\ &\cdots\cdots\cdots\cdots \\ \alpha_r &= d_{r1}Q_1 + d_{r2}Q_2 + \ldots + d_{rr}Q_r \end{aligned}\right\} \quad (4)$$

or, in matrix form,

$$\{\alpha\} = [d]\{Q\} \quad (4a)$$

In (4) the distinguishing primes used in (3a) for the aerodynamic station numbers have been omitted as no longer necessary.

It is to be noted that this equation depends only on the elastic characteristics of the structure, the coefficients d differing from ordinary elastic influence coefficients only by relating angular rather than linear displacements to the applied loads.

3. Aerodynamic Influence Coefficients

We suppose now that there is a parallel set of equations relating aerodynamic loads to the incidences that bring them into existence. To distinguish such aerodynamic loads from the general loads Q of (4) we denote them by R. Thus—

$$\left.\begin{aligned} R_1 &= e_{11}\alpha_1 + e_{12}\alpha_2 + \ldots + e_{1r}\alpha_r \\ R_2 &= e_{21}\alpha_1 + e_{22}\alpha_2 + \ldots + e_{2r}\alpha_r \\ &\cdots\cdots\cdots\cdots \\ R_r &= e_{r1}\alpha_1 + e_{r2}\alpha_2 + \ldots + e_{rr}\alpha_r \end{aligned}\right\} \quad (5)$$

or, in matrix form (using the symbolical notation of Ref. 3),

$$\{R\} = [e]\{\alpha\} \quad (5a)$$

4. Solution of Aeroelastic Problems via the Elastic and Aerodynamic Influence Coefficients

The method of using the two sets of influence coefficients—elastic and aerodynamic—in the solution of aeroelastic problems can now be given in outline, by considering various specific problems.

4.1. AERODYNAMIC FORCES (AND ACCOMPANYING WING DISTORTION) CAUSED BY CHANGE OF ROOT INCIDENCE

In considering any aeroelastic problem it is convenient to regard the resultant aerodynamic load as made up of two components—the load produced in the absence of elastic deformation, and the load directly due to such deformation. Thus, in the present case, if the rigid-body change of incidence (including displacements of control surfaces) is α_0 and the change due to elastic deformation is α_E, the total change is

$$\alpha = \alpha_E + \alpha_0 \quad . \quad . \quad . \quad (6)$$

Substituting (6) in (5*a*) we obtain a set of resultant loads

$$\{R\} = [e]\{\alpha_0 + \alpha_E\},$$
$$= [e]\{\alpha_0\} + [e]\{\alpha_E\}, \quad . \quad . \quad (7)$$

where the first term on the right hand side is completely known. Substituting now the aerodynamic loads R for the general loads Q in (4), we have, from (4*a*), the *elastic* relation between the aerodynamic loads and the "elastic" incidences α_E

$$\{\alpha_E\} = [d]\{R\} \quad . \quad . \quad . \quad (8)$$

Using (8) in (7) gives

$$\{R\} = [e]\{\alpha_0\} + [e][d]\{R\} \quad . \quad . \quad (9)$$

or,
$$(I - [e][d])\{R\} = [e]\{\alpha_0\}, \quad . \quad (9a)$$

where I = unit matrix.

The pre-multiplier of $\{R\}$ on the left hand side of (9*a*) can be expressed as a single square matrix of the same order as $[e]$ or $[d]$, and every coefficient, except the diagonals, in this resultant matrix is directly proportional to the flight speed squared. Putting

$$(I - [e][d]) = [g], \text{ say}, \quad . \quad . \quad (10)$$

we obtain for all speeds below the divergence speed of the wing, the aerodynamic loads R in terms of any arbitrary distribution of initial incidences. Thus

$$\{R\} = [g]^{-1}[e]\{\alpha_0\}$$
$$= [h]\{\alpha_0\}. \quad . \quad . \quad . \quad (11)$$

Owing to the composite character of the diagonal coefficients in the matrix g—partly constant and partly proportional to V^2 (V being the flight speed)—there is no simple relation between the loads R and the speed V for a given applied incidence. For any particular flight speed, however, the aerodynamic loads R on the wing for any given distribution of incidence can be written down as in (11). Moreover the loads, R, for a given flight speed and distribution of incidence, are (assuming equation (5) to hold) directly proportional to the magnitude of those incidences. If the actual wing distortion is required, this is at once obtained from (8), which, by (11), becomes

$$\{\alpha_E\} = [d][h]\{\alpha_0\} \quad . \quad . \quad (12)$$

In the present case α_0 is constant over the whole wing, having everywhere the value of the applied root incidence. Thus the resultant pitching moment due to an applied unit wing-root incidence can be plotted against the speed V. Such a curve can easily be linearised over any restricted range of speed so as to facilitate longitudinal stability calculations at various speeds.

4.2. WING DIVERGENCE

According to the old conception of the phenomenon, wing divergence speed is defined as the critical condition under which the positive pitching moment of the aerodynamic forces about the flexural axis becomes, at a certain critical speed, equal to the negative restoring moment of the elastic forces. The condition was regarded as depending on the wing torsional stiffness about a well-defined flexural axis. In the case of deltas and swept wings of low aspect ratio, however, there is no well-defined flexural axis, and the wing incidence in the direction of flight is governed by a composite wing deformation—partly twisting and partly bending. For wings of this type wing divergence seems best defined as the condition under which, for any disturbance from the equilibrium position (however small), the aerodynamic forces engendered grow at a faster rate than the restoring elastic forces. In other words, at and above the critical speed the slightest disturbance of the wing from the equilibrium position initiates a non-oscillatory divergence characterised by a unique form of wing displacement.

The method described here for solving this general type of wing-divergence problem again depends on the availability of the two sets of influence coefficients—elastic and aerodynamic—exemplified by equations (4) and (5).

In contrast to the problem of wing aeroelastic distortion under a *given* stimulus, such as a change of root incidence, wing distortion under divergence conditions is spontaneous. This means that the initial or rigid body change of incidence α_0 in (6) disappears, leaving only the incidence α_E due to the wing distortion itself.

In (9), therefore, we must have

$$\{R\} = [e][d]\{R\}, \quad . \quad . \quad (13)$$

or
$$[k]\{R\} = \frac{1}{V^2}\{R\}, \quad . \quad . \quad (13a)$$

where the product of $[e]$ and $[d]$, after separating the factor V^2 from $[e]$, is represented by $[k]$.

Equation (13*a*) is analogous to equation (14) of Ref. 1 and, in expanded form, becomes

$$\begin{bmatrix} k_{11}k_{12}\ldots.k_{1r} \\ k_{21}k_{22}\ldots.k_{2r} \\ \cdot\ \cdot\ \cdot\ \cdot\ \cdot \\ k_{r1}k_{r2}\ldots.k_{rr} \end{bmatrix} \begin{bmatrix} R_1 \\ R_2 \\ \cdot \\ R_r \end{bmatrix} = \begin{bmatrix} R_1 \\ R_2 \\ \cdot \\ R_r \end{bmatrix} \left(\frac{1}{V^2}\right). \qquad (14)$$

From this set of r equations, we can derive the $(r-1)$ ratios between the R's, that give via (4) the mode of the displacement, and also the critical value of V^2. The iterative process used for obtaining the fundamental frequency of an undamped dynamic system (as described in Ref. 1) is the obvious way of solving (14), and a digital computer will give the answer with expedition.

4.3. AILERON POWER

To obtain the rolling power of an aileron at any flight speed, we note that the rigid-body applied incidence α_0 consists of the direct incidence due to aileron angle and the indirect incidence due to roll, the latter varying linearly from root to tip. Thus

$$\alpha_0 = \alpha_\beta - \left(\frac{pl_c}{V}\right)\alpha_p \qquad . \qquad (15)$$

where α_β wing incidence due to aileron angle (variable with spanwise position)

α_p wing incidence due to roll, as a fraction of that at section l_c

p rolling velocity

l_c (in Sect. 4.3) convenient datum spanwise distance from plane of symmetry

V flight speed.

With this value of α_0, equation (9) becomes

$$\{R\} = [e]\left(\{\alpha_\beta\} - \frac{pl_c}{V}\{\alpha_p\}\right) + [e][d]\{R\} \qquad (16)$$

and (11) becomes

$$\{R\} = [h]\left(\{\alpha_\beta\} - \frac{pl_c}{V}\{\alpha_p\}\right). \qquad . \qquad . \qquad (17)$$

At steady rolling velocity the resultant rolling moment of the aerodynamic loads R is zero. If therefore $l_1, l_2, \ldots. l_r$ are the respective distances of stations 1, 2, ... r from the plane of symmetry, we must have

$$[l]\{R\} = [l][h]\left(\{\alpha_\beta\} - \frac{pl_c}{V}\{\alpha_p\}\right) = 0, \qquad . \quad . \quad . \quad . \quad . \quad (18)$$

a relation that gives, *for any particular flight speed V* the ratio between the rolling velocity p and the aileron angle β.

4.4. AILERON REVERSAL SPEED

To obtain the aileron reversal speed, we put p equal to zero in (18), which then gives the resultant rolling moment when rolling is prevented. As this moment is zero at the reversal speed, we need only evaluate the first term on the right hand side of (18) for two or three successive values of V and plot the corresponding curve of resultant moments. The intersection of this curve with the abscissa of zero moments gives the reversal speed.

4.5. ELEVATOR POWER

Corresponding to equations (4) and (5) for the wing, there will be two sets of influence coefficients also for the tailplane. The number of aerodynamic stations (and also "elastic" stations) will however be much fewer, since the chordwise change of incidence may well be considered constant for any particular section.

The rigid body resultant tail incidence is given by

$$\alpha_0 = \alpha_e - \left(\frac{qL}{V}\right)\alpha_q \qquad . \qquad . \qquad (19)$$

where α_e direct incidence change due to elevator angle

α_q indirect incidence change due to pitching velocity q, expressed as a fraction of that at datum point

L distance from tail datum point to c.g. of aircraft.

Writing the tail aerodynamic forces as R_T, we obtain the counterpart of (17) in the form

$$\{R_T\} = [h_T]\left(\{\alpha_e\} - \frac{qL}{V}\{\alpha_q\}\right) \qquad . \qquad (20)$$

where $$h_T = (I - [e_T][d_T])^{-1} \qquad . \qquad (21)$$

and $[e_T]$, $[d_T]$ are the aerodynamic and elastic influence matrices respectively for the tail.

At any given value of V, equation (20) gives the aerodynamic tail forces for any elevator angle and pitching velocity—including zero pitch.

The aerodynamic loads given by equations (20) and (11) provide the necessary data for including aeroelastic effects in longitudinal stability calculations.

4.6. WING FLUTTER—A POSSIBLE NEW APPROACH

The use of the two sets of influence coefficients discussed above might conceivably replace present methods of flutter investigation. The degrees of freedom, instead of being represented by the normal modes as at present, would be represented by the displacements at the several "aerodynamic" stations. The inertial, elastic, aerodynamic stiffness, and aerodynamic damping forces that appear in the flutter equations would then be expressed in terms of these displacements and their time-derivatives under an assumed frequency of oscillation. W. P. Jones[4] has already used a somewhat analogous method in his paper on "Wing-fuselage flutter of large aeroplanes." The author understands also that the English Electric Company's technical staff have recently been thinking along these lines, and have actually tried out the method on a small scale, using some half-dozen degrees of freedom to represent the motion of a tailplane.

5. Other Ways of Expressing Aerodynamic Loads in Terms of Wing Displacement

It was assumed in the treatment described that the aerodynamic loads are given in terms of a set of local incidences. It is to be pointed out, however, that, if it should be found more convenient to express them in some other way—by, for example, the average incidence and camber (or chordwise curvature) at a series of chordwise strips, the present approach is no less suitable. So long, in fact, as the aerodynamic loads can *in any way* be linearly related to the displacements of the lifting surface, as for example they are related to the incidences in the "aerodynamic" equations (5), it should always be possible to build up from the basic set (2) a corresponding set of "elastic" equations such as (4), and so provide the basis for applying the present method.

6. Concluding Remarks

The main thesis of this report is that, if aerodynamic theory can be applied in such a way as to enable the aerodynamic loads at a chosen set of wing stations to be linearly expressed in terms of the local incidence angles (or other displacement parameter) at those stations, the way is clear for solving all static aeroelastic problems for every type of wing by a standard procedure.

This follows from the fact that the problem of deriving the "elastic" influence coefficients for any type of wing has already largely been solved[2], while the further, and much simpler, problem of transforming the n^2 coefficients appropriate to the n "elastic" stations into a set of r^2 coefficients appropriate to the r "aerodynamic" equations is covered in the present paper.

It must be emphasised again that the matrix operations involved are only made possible by the capabilities of the digital computer. Granted the use of this machine, however, there is no apparent reason why the methods here described should not become standard practice in the future, and this may be taken to apply not only to "static" but also to oscillatory problems in aeroelasticity.

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Ninety-second Annual Report of the Council

1956-1957

BEFORE an audience of more than 500 the President, Mr. E. T. Jones, gave his Presidential Address on 10th January 1957, at Church House, Westminster, S.W.1, followed by a reception.

Another noteworthy event was the First Air Transport Course, sponsored by the Society, at Christ Church, Oxford. The Second Air Transport Course is to be held at Oriel College, Oxford, in March/April of this year.

It has been a busy year for the Society; membership has increased and the number of Branches also has gone up from 24 to 28.

In January the President, accompanied by the Secretary, visited New York at the request of the Institute of the Aeronautical Sciences, to discuss the possibility of the foundation of an International Aeronautical Conference, in which representatives of the aeronautical organisations of the world might take part.

The President also attended the 9th Annual General Meeting of the Indian Aeronautical Society in New Delhi, and the Secretary represented the Society at the International Air Transport Association Conference in Edinburgh.

It would appear that next session will also be full of events; already the arrangements for the Sixth Anglo-American Aeronautical Conference at Folkestone are being made, and many are eagerly looking forward to this event.

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Annual General Meeting

The 91st Annual General Meeting of the Society was held on Thursday 10th May 1956, in the Offices of the Society, with Mr. N. E. Rowe, President, in the Chair. The Report of the Council for the year and the Accounts for 1955-1956 were before the assembled Members.

The President reported that the following were elected to fill the vacancies on the Council:

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*Sir Harry Garner, K.B.E., C.B., M.A., F.R.Ae.S.

*Sir Arnold A. Hall, M.A., F.R.S., F.R.Ae.S.

M. B. Morgan, M.A., F.R.Ae.S.

F. M. Owner, C.B.E., M.Sc.(Tech.), F.R.Ae.S.

**Re-elected to Council.*

The Secretary read the names of those elected to Fellowship:

Sidney Allen	I. B. Fleming	Professor J. B. B. Owen
Dr. A. M. Ballantyne	S. F. Follett	J. G. M. Pardoe
Air Vice-Marshal G. B. Beardsworth	G. C. I. Gardiner	J. J. Parkes
Air Cdre. George Carter	Howard Giddings	R. D. Peggs
D. M. Cockburn	E. W. J. Gray	A. J. Penn
Air Vice-Marshal Sir Conrad Collier	Professor Charles Gurney	Air Vice-Marshal H. D. Spreckley
F. W. David	A. R. Howell	W. H. Stephens
K. H. Doetsch	V. A. M. Hunt	L. H. G. Sterne
Dr. J. W. Drinkwater	Dr. Dietrich Kuchemann	P. H. Stokes
J. E. P. Dunning	B. P. Laight	W. J. Strang
J. L. Edwards	Robert McIntyre	James Taylor
J. R. Ewans	Group Capt. J. R. Morgan	Professor W. J. Walker
D. J. Farrar	D. E. Morris	Air Cdre. A. H. Wheeler
	E. J. Nicholl	K. G. Wilkinson
	Air Vice-Marshal W. A. Opie	

The President presented the following Prizes:

R.P. Alston Memorial Prize	Mr. D. P. Davies
Edward Busk Memorial Prize	Mr. L. E. Fraenkel
Herbert Akroyd Stuart Memorial Prize	Mr. O. N. Lawrence
Usborne Memorial Prize	Dr. G. N. Lance
Orville Wright Prize	Mr. K. W. Gunn
Branch Prize	Mr. W. Tye
Royal Aeronautical Society Navigation Prize	Mr. J. Grierson
Pilcher Memorial Prize	Mr. H. Caplan

Mr. Rowe then inducted his successor, Mr. E. T. Jones, to the Chair and, as he did so, wished him every success and happiness in the Office.

Mr. Jones said he fully appreciated the very high honour which the Council had placed on him and he would do his very best to further the aims of the Society.

Mr. Jones said his first responsibility was to announce that the President-Elect for next year, 1957-1958, would be Mr. G. R. Edwards.

Named Lectures

The 44th Wilbur Wright Memorial Lecture was held in London on the 17th May 1956 and the subject was "The Aerodynamic Art" by Sir William S. Farren, C.B., M.B.E., F.R.S., F.R.Ae.S. (The full report was published in the July 1956 JOURNAL.)

The Twelfth British Commonwealth and Empire Lecture was held in London on the 22nd November 1956 and the subject was "Aeronautical Development in Australia and its Potential Contributions to the British Commonwealth" by Mr. L. P. Coombes, D.F.C., F.I.A.S., F.R.Ae.S. (The full report was published in the February 1957 JOURNAL.)

The Ninth Louis Bleriot Lecture was held in Paris on the 7th March 1956 and the subject was "A Philosophy of Aeronautical Research" by Mr. E. T. Jones. (The full report was published in the May 1956 JOURNAL.)

Lectures

The following Main Lectures and Section Lectures have been read before the Society in 1956/57:

1956

1st October: MAIN LECTURE AT DERBY BRANCH—The First Sir Henry Royce Memorial Lecture—Sir Henry Royce, Bart., H. I. F. Evernden, M.B.E.

9th October: SECTION LECTURE—The Pressure Jet Helicopter, A. Stepan, Dipl.-Ing. (to be published).

11th October: MAIN LECTURE AT HENLOW BRANCH—Rocket Motors, S. Allen, F.R.Ae.S.

17th October: MAIN LECTURE—The Importance of Time in Aircraft Manufacture, Air Commodore F. R. Banks, C.B., O.B.E., F.R.Ae.S.

23rd October: SECTION DISCUSSION—Functional Efficiency of Aircraft, introduced by C. Abell, O.B.E., F.R.Ae.S., and Air Vice-Marshal A. F. Hutton, C.B., C.B.E., D.F.C.

6th November: MAIN LECTURE—London Airport, Air Marshal Sir John D'Albiac, K.B.E., C.B., D.S.O.

13th November: SECTION LECTURE—Air Conditioning of Aircraft, Dr. E. W. Still, F.R.Ae.S. (to be published).

20th November: SECTION LECTURE—C. of A. Flight Testing, D. P. Davies (to be published).

22nd November: THE TWELFTH BRITISH COMMONWEALTH AND EMPIRE LECTURE—Aeronautical Development in Australia and its Potential Contributions to the British Commonwealth, L. P. Coombes, D.F.C., F.I.A.S., F.R.Ae.S.

11th December: SECTION LECTURE—Materials for Aircraft Structures Subjected to Kinetic Heating, Professor A. J. Murphy, A.F.R.Ae.S. (to be published).

20th December: ALL-DAY SECTION LECTURE on Transonic Wind Tunnel Testing Techniques (to be published). Introductory papers read by H. F. Vessey, F.R.Ae.S.; R. Hills, A.F.R.Ae.S.; J. A. Kirk, A.F.R.Ae.S.; F. O'Hara; F. E. Roe, Grad.R.Ae.S.

1957

3rd January: YOUNG PEOPLE'S LECTURE—Experiences of an Airline Pilot—Captain O. P. Jones, C.V.O., O.B.E., A.F.R.Ae.S.

8th January: SECTION LECTURE—The Significance of Flow Separation in Three Dimensions, E. C. Maskell, A.F.R.Ae.S.

10th January: PRESIDENTIAL ADDRESS—E. T. Jones, C.B., O.B.E., F.R.Ae.S.

17th January: SECTION LECTURE—Electronic Control Techniques in Aircraft Manufacture, G. S. Kermack, A.F.R.Ae.S., and H. Ogden, A.F.R.Ae.S. (to be published).

24th January: MAIN LECTURE—Aeronautical Research in the Netherlands, Professor Dr. Ir. H. J. van der Maas, F.R.Ae.S.

29th January: SECTION LECTURE—Design for Production, E. D. Keen, F.R.Ae.S. (to be published).

7th February: MAIN LECTURE AT HALTON BRANCH—Synthetic Aids to Flying Training, W. Makinson and G. M. Hellings.

12th February: JOINT LECTURE WITH THE HELICOPTER ASSOCIATION OF GREAT BRITAIN—Vibration Problems Associated with the Helicopter, O. L. L. Fitzwilliams, A.F.R.Ae.S.

14th February: MAIN LECTURE—The Fairey Delta 2, R. L. Lickley, F.R.Ae.S., and L. P. Twiss.

26th February: SECTION LECTURE—Recent Advances in the Design of Aircraft Tyres and Brakes, H. W. Trevaskis, A.F.R.Ae.S. (to be published).

7th March: THE TENTH LOUIS BLERIOT LECTURE—in London—Modern Methods of Aircraft Production, Colonel P. Badre.

12th March: SECTION LECTURE—High Temperature Materials for Engines, E. R. Gadd (to be published).

21st March: SECTION LECTURE—The Application of Automatic Digital Computers to Aeronautical Problems, Dr. S. H. Hollingdale.

26th March: MAIN LECTURE AT READING BRANCH—Problems and Prospects in Air Transport, P. G. Masefield.

Joint Conference with the Institute of Physics.—A Joint Conference of the Royal Aeronautical Society and the Stress Analysis Group of the Institute of Physics was held at the College of Aeronautics, Cranfield, on 19th, 20th and 21st September 1956. Among the many subjects discussed were: Kinetic heating, Stresses due to jet efflux, Extensometry, Instrumentation, Crack propagation. (The Jet Efflux papers were published in February 1957.)

The following Lectures will complete the Programme:

4th April: MAIN LECTURE—Engine-Airframe Integration, L. F. Nicholson, F.R.Ae.S.

9th April: SECTION LECTURE—Fail-Safe Structural Design, N. F. Harpur, Grad.R.Ae.S.

16th April: SECTION LECTURE—Simulation Techniques in Aeronautics, J. J. Foody, Grad.R.Ae.S., and R. A. Paul.

30th April: SECTION LECTURE—The Purpose and Problems of Research Aircraft, F. P. Youens, A.F.R.Ae.S.

9th May: MAIN LECTURE—THE FIRST LANCHESTER MEMORIAL LECTURE, Dr. T. von Kármán, Hon. F.R.Ae.S.

14th May: SECTION LECTURE—Reinforced Plastics for Primary Aircraft Structures, W. A. Baker, Grad.R.Ae.S.

28th May: SECTION LECTURE—Flight Instruments, F. W. Meredith, F.R.Ae.S.

Joint Symposium with the Institute of Physics

A symposium, organised jointly by the Royal Aeronautical Society and the Institute of Physics (Non-Destructive Testing Group), will be held on Thursday 30th May 1957 at the Institution of Mechanical Engineers. The symposium will deal with the Significance of the Results of Non-Destructive Testing.

First Air Transport Course, Christ Church, Oxford

The First Air Transport Course organised by the Society was held from 4th April to 18th April 1956, when 34 Students attended. A full report on the Course was published in THE JOURNAL for June 1956.

Divisions

From Australia, Professor A. V. Stephens has returned to Belfast to be the first Professor of Aeronautical Engineering at Queen's University. Professor Stephens for many years was Chairman of the Australian Division and did much to help the Society.

Mrs. D. D. Hughes (*Companion*) has replaced Air Commodore J. H. C. Wake as Secretary of the Southern African Division. Air Commodore Wake has returned to Bristol. The Council take this opportunity of thanking Air Commodore Wake for the help he gave to the Division during his Secretaryship.

During the year many of the members of the Divisions have visited Hamilton Place and have spoken of their activities and problems. Mr. L. P. Coombes, President of the Australian Division, gave the Commonwealth Lecture. This is the first time a President of a Division has done so. Air Commodore Carter also visited the Society.

Some Members of the Society have, in return, visited the Divisions, and have brought back news of good progress.

Annual Reports which we receive from the Divisions from time to time reflect the measure of their enthusiasm and activities.

Branches

The number of the Branches of the Society has now been increased to twenty-eight, four more being formed during the year. Branches have been founded at London Airport, Swindon, Southend and Cambridge, and the enthusiasm in these new Branches is very marked.

The Branches Conferences in April and October have been well attended; not yet, however, has there been a hundred per cent attendance of representatives.

Main Lectures have been held at Henlow and Halton, where the attendances were both excellent. A Main Lecture was held at Reading on Tuesday 26th March. The Council wish to congratulate the Branch Committees for the success of all such occasions.

The Memorial Lectures which are held at the Branches continue to be of the high standard with which they were begun, and they have become the outstanding lecture in the Branch programme. One new memorial lecture was inaugurated during the year—The Sir Henry Royce Memorial Lecture at the Derby Branch.

The President and Mr. Handel Davies, Chairman of the Branches Committee, have attended lectures and dinners at the Branches; on every occasion they have been impressed by the enthusiasm of the members of the Branches, and the support given to them by the Aircraft Industry and other local authorities.

The Branches have engaged in individual membership drives, both for members for the Branch and for the Society. The Weybridge Branch has now reached the remarkable figure of 647, and is now the largest Branch.

A complete list of Branches with names of the officers is published in alternate issues of THE JOURNAL. (A complete list is published this month.)

Membership

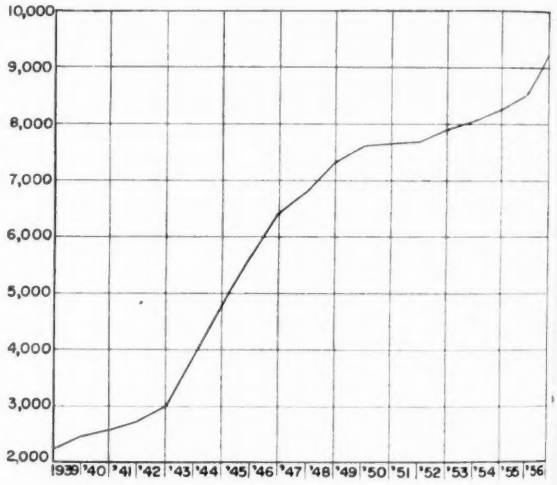
The drive to increase Membership of the Society, which was launched by Mr. N. E. Rowe in his Presidential Address in January 1956, has shown results, for there has been a substantial increase in the number of new Members, nearly three times that of the previous year.

The most outstanding increase is in the number of new Students; it is 234. Although there has been a decrease of ten in the number of Graduates, it must be noted that during the year no less than 209 Graduates have been transferred to other grades, principally to Associate Fellowship.

Even more satisfactory, and possibly more important, is the increase in the total of Associate Fellows. This increase is half as much again as last year. In view of the importance of this class of Membership to the Society, of which it is the backbone at about 43 per cent, it is very satisfactory that nearly half of the total increase in Membership is accounted for by the increase in the number of Associate Fellows.

The table opposite shows the membership figures as at 31st December 1956.

The graph shows membership growth from 1939 to 1956.



Graduates' and Students' Section

During the year April 1956-March 1957, the Graduates' and Students' Committee has continued to organise a wide range of activities ranging from the conventional lecture to the unconventional party. The average attendance at lectures has unfortunately been considerably smaller than in previous years, a fact which is partly due to the present fuel shortage and partly due to a malaise which is also affecting other societies. The visits have been, as usual, exceptionally well attended, and the numbers of visitors attending have been on the average 90 per cent of the maximum permitted number.

Lectures and Visits: The lecture programme has once more been made up of lectures of broad interest as opposed to detailed lectures of a specialised nature. As in previous years the aim has been to bring the younger members of the Society into contact with the broad net of modern

aeronautical science and engineering. A particularly successful lecture was that by Mr. E. P. Hawthorne, Chief Executive of Hawker Siddeley Nucleonics, who lectured on "Atomic Propulsion for Aircraft." This lecture was written up extensively in the aeronautical and daily press.

Visits were paid to R.A.F. and U.S.A.F. Stations, to research establishments and an aircraft manufacturer, and also to a manufacturer of sports racing cars whose advanced structural and aerodynamic design reflects aeronautical practice.

Social Occasions: During the summer a most successful informal party was held at 4 Hamilton Place. It is hoped to repeat it in 1957. In November 1956 the Section's Annual Dance at 4 Hamilton Place once more broke its attendance records and achieved what is now becoming its usual success.

Other Activities: It is believed that the organisation of technical lectures and visits is only a small part of the functions of the Section. Equally important is the necessity to reflect accurately the views of Students and Graduates to the Society. To this end, the Section's monthly page in THE JOURNAL has been most useful and has proved a valuable line of contact with Section Members.

It is extremely gratifying to note that about 60 per cent of all new elections to the Society in the year January-December 1956 were in the Graduate or Student Grade.

Finally, the Council would like to thank all those who have given lectures to the Section and arranged for visits to their establishments in the past year.

LIST OF LECTURE MEETINGS DURING 1956-57

1956

6th March: Annual General Meeting and Film Show.

28th March: Artificial Space Satellites by A. V. Cleaver.

18th April: Gas Turbines—Propeller or Jet? by R. M. Fitzgerald.

10th May: Some Thoughts on Present Day Aircraft and the Future by Sir Frederick Handley Page.

28th September: Novel Methods of Take-off and Landing by T. J. Cummings.

10th October: Service Flight Testing of High Speed Aircraft by Sqn. Ldr. P. D. Thorne.

30th October: Nuclear Power for Aircraft by E. P. Hawthorne.

23rd November: Effects of Kinetic Heating on Aircraft Structures by A. W. Kitchenside (to be published).

7th December: Film Show.

1957

15th January: N. E. Rowe Medal Lectures (to be published).

13th February: The Area Rule by W. T. Lord.

5th March: Annual General Meeting and Film Show.

19th March: Gas Turbines for Helicopters by A. W. Morley.

The following Lectures will complete the Programme:

1957

17th April: Problems and Prospects in Air Transport by P. G. Masefield.

15th May: Guided Weapon Research and Development by W. H. Stephens.

List of Visits during 1956-57

1956

7th April: R.A.F., West Malling.

18th May: U.S.A.F., Upper Heyford.

9th June: Handley Page.

12th September: Boscombe Down.

22nd September: National Physical Laboratory.

17th October: Royal Aircraft Establishment.

1957

29th January: Lotus Engineering Company.

16th February: Southern Air Traffic Control Centre.

20th March: Southern Air Traffic Control Centre (repeat visit).

MEMBERSHIP AT 31st DECEMBER 1956

Grade	London Register		Australian Division		New Zealand Division		Southern Africa Division		Life and Honorary		Totals		Suspended London Register Members (included in the foregoing figures)	
Fellows	407	(374)	14	(14)	4	(3)	3	(1)	(H) 29 (L) 18	(49)	475	(441)	1	(1)
Associate Fellows	3,728	(3,410)	139	(121)	33	(29)	57	(51)	(L) 18	(17)	3,975	(3,628)	76	(61)
Associates	2,020	(1,907)	73	(66)	62	(57)	82	(76)	(L) 5	(5)	2,242	(2,111)	85	(74)
Graduates	1,213	(1,217)	56	(61)	7	(8)	5	(5)	—	(—)	1,281	(1,291)	37	(35)
Students	1,016	(781)	42	(40)	6	(6)	7	(10)	—	(—)	1,071	(837)	49	(64)
Founder Members	12	(13)	—	(—)	—	(—)	—	(—)	(L) 1	(1)	13	(14)	—	(—)
Companions	155	(151)	9	(7)	4	(4)	7	(5)	(H) 3 (L) 7	(10)	185	(177)	5	(4)
Temporary Honorary Members	—	(—)	—	(—)	—	(—)	—	(—)	53	(51)	53	(51)	—	(—)
	8,551	(7,853)	333	(309)	116	(107)	161	(148)	134	(133)	9,295	(8,550)	253	(239)

Figures in brackets are corresponding figures at 31st December 1955

THE ROYAL

(INCORPORATED

BALANCE SHEET

1955 Figures £		£ s. d.	£ s. d.	£ s. d.
	CURRENT LIABILITIES			
9981	Sundry Creditors		6336 13 3	
4988	Subscriptions and other amounts received in advance		5101 7 3	
				11438 0 6
	SURPLUS (subject to depreciation of Investments)			
	Reserve for Anglo-American Conferences			
	Balance at 31st December 1955		1934 17 2	
	Add transfer from Income and Expenditure Account		1500 0 0	
			3434 17 2	
	Deduct Expenditure less receipts during year		525 10 8	
1935			2909 6 6	
	Income and Expenditure Account			
	Balance at 31st December 1955	15133 1 11		
	Add Surplus of Income over Expenditure for year to date	1897 11 7		
			17030 13 6	
15133				19940 0 0
£32037				£31378 0 6

E. T. JONES,
President.

G. P. BULMAN,
Honorary Treasurer.

REPORT OF THE AUDITORS TO THE MEMBERS

In our opinion the above balance sheet and the annexed income and Society Endowment Fund included in the annexed accounts of Aeronautical Trusts Ltd., and of its surplus for the year ended on that date.

We have obtained all the information and explanations which we considered in agreement with them and the said information and explanations.

3 Frederick's Place, Old Jewry, London, E.C.2.
26th March 1957.

AERONAUTICAL SOCIETY

BY ROYAL CHARTER 1949)

31st DECEMBER 1956

1955 Figures £		£ s. d.	£ s. d.
	CURRENT ASSETS		
1	Stock of Journals and other publications	1 0 0	
13171	Sundry Debtors	11444 15 9	
700	Payments in advance	77 8 8	
7107	Balances at Bank and Cash in Hand	8606 12 3	
			20129 16 8
5600	INVESTMENTS AT COST Market value 31st December 1956 £4,354 (1955 £4,543)		5600 0 0
	AERONAUTICAL TRUSTS LIMITED		
1	21 shares of 1/- each fully paid at cost	1 1 0	
63	Amounts due on current account	253 7 10	
			254 8 10
	PRINTED BOOKS, BINDINGS, OLD PRINTS, ETC.		
50	At nominal amount		50 0 0
	NASH COLLECTION OF HISTORICAL AIRCRAFT		
5344	At cost		5343 15 0
£32037			£31378 0 6

OF THE ROYAL AERONAUTICAL SOCIETY

expenditure account of the Society, together with the accounts of the Royal Aeronautical give a true and fair view of the state of the Society's affairs as at 31st December 1956,

necessary. In our opinion the Society has kept proper books, and the said accounts are

(*Signed*) PRICE WATERHOUSE & CO.

THE ROYAL

INCOME AND EXPENDITURE ACCOUNT

1955 Figures			£ s. d.	£ s. d.
£				
		ESTABLISHMENT EXPENSES		
3437		Ground Rent, Heating, Lighting, Insurance and Repairs		2974 14 6
		ADMINISTRATIVE AND OFFICE EXPENSES		
10699		Salaries and National Insurance	12911 8 11	
1539		Pension and Pension Premiums	1645 7 7	
2083		Printing and Stationery	2753 14 4	
1689		Postages and Telephones	2051 14 8	
329		Office Furniture and Equipment	404 0 11	
469		Travelling Expenses	453 10 4	
1174		Other Charges	844 16 7	
	17982			21064 13 4
		JOURNAL AND PUBLICATIONS		
3956		Salaries and Pension Premiums	4324 11 5	
19083		Printing	20500 1 1	
3186		*Printing Year Book*	—	
2611		Postages and Envelopes	3260 6 7	
1611		Other Expenses	1399 7 3	
	30447			29484 6 4
		TECHNICAL COMMITTEES		
6905		Salaries and Pension Premiums	6660 16 2	
4320		Printing and other charges	3997 10 11	
81		Travelling Expenses	135 1 10	
	11306			10793 8 11
		GARDEN PARTY		
		Expenses		2332 2 10
	606	EXAMINATIONS EXPENSES		540 15 7
	567	MEETINGS		647 6 2
	1500	ANGLO-AMERICAN AERONAUTICAL CONFERENCES RESERVE		1500 0 0
	563	DINNERS AND RECEPTIONS		678 10 9
		LIBRARY		
1603		Salaries and Pension Premiums	1687 10 9	
346		Expenses	378 4 8	
	1949			2065 15 5
	560	GRANTS TO BRANCHES AND SECTIONS		565 0 0
	266	PRIZES AND DONATIONS		248 12 0
	300	CHARTER SCHOLARSHIPS		300 0 0
	306	LEGAL AND PROFESSIONAL CHARGES		288 14 0
	364	PAYMENT TO CANADIAN AERONAUTICAL INSTITUTE		367 6 6
	500	*CONTRIBUTION TOWARDS COST OF CAPTAIN PRITCHARD'S LECTURE TOUR IN U.S.A.*		—
	630	BALANCE, BEING SURPLUS OF INCOME OVER EXPENDITURE FOR YEAR, CARRIED TO BALANCE SHEET		1897 11 7
	£71283			£75748 17 11

AERONAUTICAL SOCIETY

FOR THE YEAR ENDED 31st DECEMBER 1956

1955 Figures				
£		£ s. d.	£ s. d.	
25738	ANNUAL SUBSCRIPTIONS		27771 0 9	
11214	DONATIONS AND GRANTS		10860 17 6	
168	INTEREST ON INVESTMENTS (GROSS)	168 0 0		
	INTEREST ON DEPOSIT ACCOUNT AT BANK	225 16 5		
5230	SURPLUS ON ENDOWMENT FUND INCOME AND EXPENDITURE ACCOUNT FOR YEAR	5425 8 11		
5398			5819 5 4	
	JOURNAL AND PUBLICATIONS			
14948	Advertising Revenue	15585 15 11		
1875	*Advertising Revenue, Year Book*	—		
16823				
8583	Sales	9007 10 11		
25406			24593 6 10	
	TECHNICAL COMMITTEES			
2870	Sales		3727 14 6	
	GARDEN PARTY			
	Sale of Tickets	1887 19 6		
	Profit on Programme	599 2 0		
			2487 1 6	
657	EXAMINATIONS FEES		489 11 6	
£71283			£75748 17 11	

AERONAUTICAL

BALANCE SHEET

1955 Figures £		£ s. d.	£ s. d.	£ s. d.
	SHARE CAPITAL			
	AUTHORISED: 40 shares of 1s. each		2 0 0	
1	ISSUED: 21 shares of 1s. each fully paid			1 1 0
	ROYAL AERONAUTICAL SOCIETY ENDOWMENT FUND			
	CAPITAL ACCOUNT			
134369	Balance at 31st December 1955		135222 13 8	
854	*Add* Entrance Fees received during year		1130 17 0	
—	Donations received during year		213 1 0	
			136566 11 8	
	INCOME ACCOUNT			
9104	Balance as at 31st December 1955		9103 14 6	
144328				145670 6 2
	ROYAL AERONAUTICAL SOCIETY EDUCATION FUND			
	INCOME ACCOUNT			
—	Surplus of Income over Expenditure for year to date			484 13 9
	EDWARD BUSK STUDENTSHIP IN AERONAUTICS			
	CAPITAL ACCOUNT			
5421	As at 31st December 1955		5420 10 4	
—	*Add* Premium on conversion of investment		3 0 0	
			5423 10 4	
	INCOME ACCOUNT			
204	Balance at 31st December 1955	293 16 1		
90	*Add* Income for year to date	249 11 9		
		543 7 10		
	Less Transfer to Royal Aeronautical Society			
—	Education Fund	543 7 10		
5715			—	5423 10 4
150043	*Forward*			151579 11 3

TRUSTS LIMITED

31st DECEMBER 1956

1955 Figures £		£ s. d.	£ s. d.	£ s. d.
1	CASH IN HAND			1 1 0
	ROYAL AERONAUTICAL SOCIETY ENDOWMENT FUND			
	Leasehold Property at cost *less* amounts written off 4, 8 and 9 Hamilton Place			
	At cost	14185 1 9		
	Less Amortisation written off to date	9746 1 9		
5094			4439 0 0	
	Furniture at cost *less* depreciation			
	At cost	6396 1 11		
	Less Depreciation written off to date	4224 1 11		
2492			2172 0 0	
133859	Investments at cost		133859 1 11	
	Market value 31st December 1956 £106,914 (1955 £114,381)			
			140470 1 11	
	Current Assets			
375	Sundry Debtors	375 0 0		
2570	Balance at Bank	4853 12 1		
			5228 12 1	
144391			145698 14 0	
63	*Less* Amount due to the Royal Aeronautical Society		28 7 10	
144328				145670 6 2
	ROYAL AERONAUTICAL SOCIETY EDUCATION FUND			
—	Balance at Bank		338 15 10	
—	Amount due from Edward Busk Studentship in Aeronautics		249 11 9	
—	Amount due from Geoffrey de Havilland Memorial Fund		121 6 2	
			709 13 9	
—	*Less* Amount due to Royal Aeronautical Society		225 0 0	
				484 13 9
	EDWARD BUSK STUDENTSHIP IN AERONAUTICS			
	Investments at valuation 31st December 1951		4806 10 0	
	Investments at cost		601 6 6	
5408			5407 16 6	
	Market value 31st December 1956 £4,890 (1955 £5,209)			
307	Balance at Bank		265 5 7	
			5673 2 1	
	Less Amount due to Royal Aeronautical Society Education Fund ..		249 11 9	
5715				5423 10 4
150043	*Forward*			151579 11 3

BALANCE SHEET—*Continued*

1955 Figures £		£ s. d.	£ s. d.	£ s. d.
150043	*Forward*			151579 11 3
	GEOFFREY DE HAVILLAND MEMORIAL FUND			
	CAPITAL ACCOUNT			
4176	As at 31st December 1955		4175 17 5	
	INCOME ACCOUNT			
341	Balance at 31st December 1955	361 16 5		
21	*Add* Surplus of Income over Expenditure for year to date	106 2 10		
		467 19 3		
—	*Less* Transfer to Royal Aeronautical Society Education Fund	467 19 3	—	
4538				4175 17 5
	WILBUR WRIGHT MEMORIAL FUND			
	CAPITAL ACCOUNT			
2212	As at 31st December 1955		2211 17 11	
	INCOME ACCOUNT			
183	Balance at 31st December 1955	174 2 6		
9	*Less* Excess of Expenditure over Income for year to date	19 1 8	155 0 10	
2386				2366 18 9
	EDWARD BUSK MEMORIAL FUND			
	CAPITAL ACCOUNT			
449	As at 31st December 1955		449 6 1	
	INCOME ACCOUNT			
246	Balance at 31st December 1955	249 16 3		
4	*Add* Surplus of Income over Expenditure for year to date	3 10 4	253 6 7	
699				702 12 8
	PILCHER MEMORIAL FUND			
	CAPITAL ACCOUNT			
100	As at 31st December 1955		99 14 0	
	INCOME ACCOUNT			
75	Balance at 31st December 1955	80 6 0		
5	*Less* Excess of Expenditure over Income for year to date	5 2 8	75 3 4	
180				174 17 4
	USBORNE MEMORIAL FUND			
	CAPITAL ACCOUNT			
109	As at 31st December 1955		109 2 5	
	INCOME ACCOUNT			
85	Balance at 31st December 1955	80 13 8		
5	*Less* Excess of Expenditure over Income for year to date	4 10 8	76 3 0	
189				185 5 5
	HERBERT AKROYD STUART FUND			
	CAPITAL ACCOUNT			
691	As at 31st December 1955		691 9 0	
	INCOME ACCOUNT			
677	Balance at 31st December 1955	702 16 10		
26	*Add* Surplus of Income over Expenditure for year to date	24 0 6	726 17 4	
1394				1418 6 4
159429	*Forward*			160603 9 2

TRUSTS LIMITED

31st DECEMBER 1956

1955 Figures £		£ s. d.	£ s. d.
150043	*Forward*		151579 11 3
	GEOFFREY DE HAVILLAND MEMORIAL FUND		
4427	Investments at cost	4175 17 5	
	Market value 31st December 1956 £3,013 (1955 £3,451)		
111	Balance at Bank	121 6 2	
		4297 3 7	
	Less Amount due to Royal Aeronautical Society Education Fund ..	121 6 2	
4538			4175 17 5
	WILBUR WRIGHT MEMORIAL FUND		
2251	Investments at cost	2250 14 9	
	Market value 31st December 1956 £1,980 (1955 £2,091)		
135	Balance at Bank	116 4 0	
2386			2366 18 9
	EDWARD BUSK MEMORIAL FUND		
658	Investments at cost	658 8 8	
	Market value 31st December 1956 £517 (1955 £559)		
41	Balance at Bank	44 4 0	
699			702 12 8
	PILCHER MEMORIAL FUND		
156	Investment at cost	156 5 0	
	Market value 31st December 1956 £108 (1955 £118)		
24	Balance at Bank	18 12 4	
180			174 17 4
	USBORNE MEMORIAL FUND		
175	Investment at cost	174 11 1	
	Market value 31st December 1956 £121 (1955 £131)		
15	Balance at Bank	10 14 4	
189			185 5 5
	HERBERT AKROYD STUART FUND		
1278	Investments at cost	1278 11 1	
	Market value 31st December 1956 £910 (1955 £987)		
116	Balance at Bank	139 15 3	
1394			1418 6 4
159429	*Forward*		160603 9 2

BALANCE SHEET—*Continued*

1955 Figures £		£ s. d.	£ s. d.	£ s. d.
159429	*Forward*			160603 9 2
	R.38 MEMORIAL FUND			
	CAPITAL ACCOUNT			
982	As at 31st December 1955	.. ..	981 13 10	
	INCOME ACCOUNT			
1175	Balance at 31st December 1955	1147 10 9		
28	*Add* Income for year to date	69 11 8	1217 2 5	
2129				2198 16 3
	SIMMS GOLD MEDAL FUND			
	CAPITAL ACCOUNT			
528	As at 31st December 1955	.. ..	527 15 9	
	INCOME ACCOUNT			
106	Balance at 31st December 1955	121 7 1		
15	*Add* Surplus of Income over Expenditure for year to date	13 5 10	134 12 11	
649				662 8 8
	ALSTON MEMORIAL FUND			
	CAPITAL ACCOUNT			
250	As at 31st December 1955	.. ..	250 8 10	
	INCOME ACCOUNT			
84	Balance at 31st December 1955	85 4 7		
1	*Add* Surplus of Income over Expenditure for year to date	1 3 0	86 7 7	
335				336 16 5
£162542				£163801 10 6

REPORT OF THE AUDITORS TO THE

In our opinion the foregoing accounts give a true and fair view of the state and of the surplus of the Funds for the year ended on that date.

We have obtained all the information and explanations which we considered which are in agreement with them and with the said information and explanations, give

3 Frederick's Place, Old Jewry, London, E.C.2.
26th March 1957.

TRUSTS LIMITED

31st DECEMBER 1956

1955 Figures £		£ s. d.	£ s. d.
159429	*Forward*		160603 9 2
	R.38 MEMORIAL FUND		
2005	Investments at cost	2004 18 9	
	Market value 31st December 1956 £1,407 (1955 £1,525)		
124	Balance at Bank	193 17 6	
2129			2198 16 3
	SIMMS GOLD MEDAL FUND		
585	Investments at cost	585 0 0	
	Market value 31st December 1956 £436 (1955 £466)		
64	Balance at Bank	77 8 8	
649			662 8 8
	ALSTON MEMORIAL FUND		
295	Investment at cost	295 2 10	
	Market value 31st December 1956 £225 (1955 £244)		
40	Balance at Bank	41 13 7	
335			336 16 5
£162542			£163801 10 6

MEMBERS OF AERONAUTICAL TRUSTS LTD.

of the Company's affairs and of the Funds administered by it as at 31st December 1956,

necessary. In our opinion the Company has kept proper books, and the said accounts, in the prescribed manner the information required by the Companies Act, 1948.

(*Signed*) PRICE WATERHOUSE & CO.

AERONAUTICAL

INCOME AND EXPENDITURE ACCOUNTS

ROYAL AERONAUTICAL SOCIETY

1955 Figures £		£ s. d.
655	Amortisation of Leasehold Property	655 0 0
320	Depreciation of Furniture	320 0 0
8	Legal Expenses	8 8 0
5230	Surplus of Income over Expenditure for year, transferred to the Royal Aeronautical Society	5425 8 11
£6213		£6408 16 11

ROYAL AERONAUTICAL SOCIETY

£		£ s. d.
	Grants made in 1956	826 13 4
	Surplus of Income over Expenditure for year, carried to Balance Sheet	484 13 9
		£1311 7 1

EDWARD BUSK STUDENTSHIP

£		£ s. d.
90	Income for year, carried to Balance Sheet	249 11 9
135	*1955 Awards*	—
£225		£249 11 9

GEOFFREY DE HAVILLAND

£		£ s. d.
	Loss on sale of investment	15 3 4
113	*1955 Award*	—
21	Surplus of Income over Expenditure for year, carried to Balance Sheet	106 2 10
£134		£121 6 2

WILBUR WRIGHT

£		£ s. d.
100	1956 Award	100 0 0
£100		£100 0 0

EDWARD BUSK

£		£ s. d
21	1956 Award	21 0 0
3	Surplus of Income over Expenditure for year, carried to Balance Sheet	3 10 4
£24		£24 10 4

TRUSTS LIMITED

FOR THE YEAR ENDED 31st DECEMBER 1956

ENDOWMENT FUND

1955 Figures £		£ s. d.
2617	Interest on Investments (Gross)	2617 1 4
1240	Interest on Investments (*less* tax)	1357 0 8
856	Refund of Income Tax	934 14 11
1500	Rents Receivable	1500 0 0
£6213		£6408 16 11

EDUCATION FUND

£		£ s. d.
	Contribution from Royal Aeronautical Society (Charter Scholarship)	300 0 0
	Transfer from Edward Busk Studentship in Aeronautics	543 7 10
	Transfer from Geoffrey de Havilland Memorial Fund	467 19 3
		£1311 7 1

IN AERONAUTICS

£		£ s. d.
136	Interest on Investments (Gross)	224 12 0
40	Refund of Income Tax	24 19 9
49	*Interest on Investments (less tax)*	—
£225		£249 11 9

MEMORIAL FUND

£		£ s. d.
132	Interest on Investments (Gross)	121 6 2
2	*Refund of Income Tax*	—
£134		£121 6 2

MEMORIAL FUND

£		£ s. d.
81	Interest on Investments (Gross)	80 18 4
10	*Refund of Income Tax*	—
9	Excess of Expenditure over Income for year, carried to Balance Sheet	19 1 8
£100		£100 0 0

MEMORIAL FUND

£		£ s. d.
24	Interest on Investments (Gross)	24 10 4
£24		£24 10 4

AERONAUTICAL

INCOME AND EXPENDITURE ACCOUNTS

PILCHER

1955 Figures £		£ s. d.
	1956 Award	10 10 0
5	*Income for year, carried to Balance Sheet*	—
£5		£10 10 0

USBORNE

£		£ s. d.
10	1956 Award	10 10 0
£10		£10 10 0

HERBERT AKROYD

£		£ s. d.
21	1956 Award	21 0 0
26	Surplus of Income over Expenditure for year, carried to Balance Sheet	24 0 6
£47		£45 0 6

R.38

£		£ s. d.
	Income for year, carried to Balance Sheet	69 11 8
100	*1955 Awards*	—
£100		£69 11 8

SIMMS GOLD

£		£ s. d.
6	1956 Award	6 9 6
15	Surplus of Income over Expenditure for year, carried to Balance Sheet	13 5 10
£21		£19 15 4

ALSTON

£		£ s. d.
10	1956 Award	10 0 0
1	Surplus of Income over Expenditure for year, carried to Balance Sheet	1 3 0
£11		£11 3 0

TRUSTS LIMITED

FOR THE YEAR ENDED 31st DECEMBER 1956—*Continued*

MEMORIAL FUND

1955 Figures			
£		£	s. d.
5	Interest on Investments (Gross)	5	7 4
	Excess of Expenditure over Income for year, carried to Balance Sheet	5	2 8
£5		£10	10 0

MEMORIAL FUND

£		£	s. d.
6	Interest on Investments (Gross)	5	19 4
4	Excess of Expenditure over Income for year, carried to Balance Sheet	4	10 8
£10		£10	10 0

STUART FUND

£		£	s. d.
45	Interest on Investments (Gross)	45	0 6
2	*Refund of Income Tax*		—
£47		£45	0 6

MEMORIAL FUND

£		£	s. d.
70	Interest on Investments (Gross)	69	11 8
2	*Refund of Income Tax*		—
28	*Excess of Expenditure over Income for year, carried to Balance Sheet*		
£100		£69	11 8

MEDAL FUND

£		£	s. d.
20	Interest on Investments (Gross)	19	15 4
1	*Refund of Income Tax*		—
£21		£19	15 4

MEMORIAL FUND

£		£	s. d.
11	Interest on Investments (Gross)	11	3 0
£11		£11	3 0

Honours Awarded to Members

Members of the Society have been honoured by Her Majesty the Queen during the year. These the Council have much pleasure in congratulating.

Other Honours have been conferred upon Members of the Society by learned Societies and other bodies; the Council also congratulates these Members.

BIRTHDAY HONOURS LIST 1956

Knight Commander of the Bath—Air Vice-Marshal T. N. McEvoy (*Associate Fellow*).

Knight Bachelor—
Mr. H. W. Clarke (*Fellow*).
Mr. G. H. Dowty (*Fellow*).

Imperial Service Order—
Mr. C. Howarth (*Fellow*).

Order of the British Empire—
Mr. L. Boddington (*Fellow*).

NEW YEAR'S HONOURS LIST 1957

Knight bachelor—
G. R. Edwards (*Fellow*) (*President-Elect*)

Commander of the Order of the British Empire—
Mr. James Martin (*Fellow*).
Air Commodore M. E. M. Perkins (*Associate Fellow*).
Group Captain F. F. Wicks (*Associate Fellow*).

Officer of the Order of the British Empire—
Group Captain J. H. Hunter-Tod (*Associate Fellow*).
Mr. A. Mathisen (*Associate Fellow*).
Group Captain A. J. Mott (*Associate Fellow*).
Mr. R. D. Peggs (*Fellow*).
Mr. A. J. Penn (*Fellow*).
Wing Commander R. C. Preston (*Associate Fellow*).

Member of the Order of the British Empire
Group Captain R. G. Slade (*Associate Fellow*).

AMERICAN HONOURS AWARDED TO MEMBERS

The National Aeronautic Association's Elder Statesmen of Aviation Award Committee have presented awards to the following members of the Society:

Mr. Igor I. Sikorsky (*Honorary Fellow*).
Mr. Grover Loening (*Fellow*).

The Institute of the Aeronautical Sciences have included the following members in their award list:

Honorary Fellowship to Air Commodore F. R. Banks (*Fellow*).

Fellowship to Professor A. R. Collar (*Fellow*).

Fellowship to Mr. Stewart Scott Hall (*Fellow*).

Edwin E. Aldrin (*Associate Fellow*) and Earl D. Osborn (*Associate Fellow*) were elected Vice-Presidents of the Institute of the Aeronautical Sciences.

The Wright Brothers' Memorial Trophy for 1955 was awarded to Dr. H. L. Dryden (*Honorary Fellow*). The award has been made annually since 1948 for "significant public service of enduring value to aviation in the United States."

CANADIAN AERONAUTICAL INSTITUTE

The following Members of the Society have been elected Fellows of the Canadian Aeronautical Institute:

Mr. I. M. Hamer (*Associate Fellow*).

Air Vice-Marshal A. L. James (*Fellow*).

Mr. B. S. Shenstone (*Fellow*).

SIR FREDERICK HANDLEY PAGE

The Queen approved the appointment of Sir Frederick Handley Page (*Honorary Fellow*) as her Majesty's Lieutenant for Middlesex in place of Lord Latham, resigned.

GUILD OF AIR PILOTS AND AIR NAVIGATORS

Mr. L. A. Wingfield (*Associate*) was presented with an inscribed silver salver by the Guild of Air Pilots and Air Navigators on 17th October 1956 in appreciation of his 27 years' service as Clerk of the Guild.

The Derry and Richards Memorial Medal

The Derry and Richards Memorial Medal, awarded each year by the Guild of Air Pilots and Air Navigators for experimental flying, was presented for the year 1955 to Mr. Peter Twiss (*Associate Fellow*), of Fairey Aviation Ltd., for his work on high speed delta aircraft leading up to the World Air Speed Record runs.

Honorary Fellows

The Council has pleasure in announcing that the following were accorded the honour of Honorary Fellowship of the Society in 1956:

Sir Roy H. Dobson, C.B.E., J.P., F.R.Ae.S.
Dr. Hugh L. Dryden, Hon.F.I.A.S., F.R.Ae.S.

The Scrolls of Honorary Fellowship were presented at the 44th Wilbur Wright Memorial Lecture on 17th May 1956.

Medals and Awards of the Society

Full particulars of the Medals and Awards of the Society were published in the JULY 1956 JOURNAL.

Elliott Memorial Prize

The Elliott Memorial Prize has been awarded to the following:

Flight Sergeant Apprentice J. J. McMahon of the April 1953 Entry.

Corporal Apprentice D. Holcroft of the September 1953 Entry.

Leading Apprentice D. R. Carr-Hyde of the January 1954 Entry.

The Prize is presented for the highest marks obtained in the General Studies Examination at Halton.

E. J. N. Archbold Memorial Prize

The E. J. N. Archbold Memorial Prize for 1955 has been awarded to John Timothy Greenslade, a student apprentice at the Royal Aircraft Establishment Technical College, Farnborough.

Baden-Powell Memorial Prize

The Baden-Powell Memorial Prize, awarded to the best candidate in Part II of the June 1956 Associate Fellowship Examination, was awarded to Mr. B. Gumpel.

Royal Aeronautical Society Prizes in Aeronautics

The following Royal Aeronautical Society Prizes in Aeronautics for 1956 were awarded by the Council. The Society's Prizes in Aeronautics are awarded to the best student in The Aeronautical Department in each case.

University of Glasgow: Mr. Douglas Henry Jagger.
University of Cambridge: Mr. John Glynn Jones.
University of Bristol: Mr. D. Isaacs.
Imperial College of Science and Technology: Mr. G. E. Cook.
College of Aeronautics: Mr. J. R. Hatfield.
Queen Mary College: Mr. C. S. Leyman and Mr. B. M. Wood.
University of Southampton: Mr. J. H. Foxwell.

SCHOLARSHIPS

The Charter Scholarship: Mr. G. E. Cook of Coventry.

The Edward Busk Studentship in Aeronautics: Mr. R. W. Roberts of Birmingham.

The Geoffrey de Havilland Memorial Scholarship: Mr. D. M. Squires of Bishop's Stortford.

GRANTS FROM THE EDUCATION FUND

Grants in aid of further study and research in aeronautics have been awarded to the following:

Mr. M. G. Bader
Mr. T. J. Black
Mr. E. M. Cowburn
Mr. J. I. Dodds
Mr. D. J. Huggett
Mr. N. E. Phelps

Journal Premium Awards

A list of Premium Awards made in 1955 was published in the May 1956 issue of the JOURNAL of the Society.

Finance

The Income and Expenditure Accounts and Balance Sheets of The Royal Aeronautical Society and the Aeronautical Trusts Limited for 1956 are published with this Report (pp. 258 to 272).

Officers and Committees

The Council has been very well served over the year by the hard-working Members of the Committees of the Society. The work of some of the Committees is arduous and entails the Members giving up much of their own time. The Council is grateful to them.

Technical

The scope of the work of the Society's Technical Department continues to increase and during 1956 considerable progress has again been made.

Twenty-one new Structures Data Sheets have been completed since the last annual report and are ready for circulation to subscribers. In this issue are included sheets on a range of sections under combined bending and axial load beyond the limit of proportionality, the extension of data appropriate to plates under normal loading, the considerable extension of data on stress concentration factors and the buckling of flat sandwich panels in compression. Several groups of existing data sheets are being reviewed in detail to ensure that they present the most up-to-date information available and a number have been reprinted or are being revised.

For many years the Society's Structures Committee has appreciated the importance of fatigue in aircraft design but for some time it was felt that actual fatigue behaviour was too scattered and unreliable to form the basis for a data sheet series. After a general survey of the position, the Committee, as a first step, initiated a series of data sheets on stress concentration factors. In 1955 the Fatigue Committee was formed to relieve the Structures Committee and was mainly concerned with various programmes of fatigue investigation in which the Society was collaborating. Again, during the year under review, further results on these programmes have become available and some have been reported in the AERONAUTICAL QUARTERLY. Within recent months the Fatigue Committee has found it possible to start consideration of data sheets on fatigue behaviour and a provisional list has been drawn up which is now receiving detailed consideration by the Committee and the Technical Department.

Once more the work of extension and revision of the Aerodynamic Data Sheets has continued and during the past year sixteen new sheets were completed and are now in the process of being distributed to subscribers. It is of note that this group of sheets, although slightly smaller in number than in the previous year, is greater in technical content than most issues. The increasing complexity of the subjects now being covered in Aerodynamics Data Sheets necessitates the presentation of the information on several pages of curves and text; thus one "data sheet" often consists of several pages. The sheets issued covered a number of new subjects in addition to revising existing information. Foremost among the new matters covered were the properties of two-dimensional supersonic aerofoils, the aerodynamic centre of wings at subsonic and supersonic speeds, pressure distribution on two- and three-dimensional blunt noses at supersonic speeds and the properties of the atmosphere at altitudes up to 250,000 ft. This latter work has aroused considerable interest in both the aircraft and missile fields. Reprinting of data sheets has continued where necessary.

The Performance Committee has now recommenced its activities and is working in close co-operation with the Aerodynamics Committee. One of the first tasks due to be undertaken is a review of the existing Performance Data Sheets in order to ascertain whether revisions are necessary. Attempts will be made to prepare new Data Sheets on Supersonic Performance Estimation and on the energy rate of climb technique among other subjects.

Subsequent to the Fuels and Oils Committee's approval of new and revised sheets a supplementary issue was prepared and sent to all holders of the original volume. About one half of the original set on aviation fuels was revised and new sheets indicated the solubility of air and the change of specific gravity with temperature. New lubricating oil sheets included information on both mineral and synthetic oils and dealt particularly with such aspects as methods of test, specification requirements and characteristics of various oils. No further work on Fuels and Lubricants Data Sheets is at present being undertaken or contemplated.

TECHNICAL COMMITTEES

Structures Committee

Mr. H. B. Howard (*Chairman*)	Mr. E. D. Keen
Mr. H. L. Cox	Mr. E. H. Mansfield
Professor W. S. Hemp	Mr. F. Tyson
Mr. D. James	Mr. K. L. C. Legg

Aerodynamics Committee

Professor A. D. Young (*Chairman*)	Mr. R. Melling
Mr. R. Dickson	Mr. R. A. Shaw
Mr. P. J. Duncton	Mr. J. C. Stevenson
Mr. J. W. Fozard	Mr. H. H. B. M. Thomas
Dr. D. W. Holder	Mr. A. K. Weaver

Performance Committee

Mr. Handel Davies (*Chairman*)	Mr. C. F. Toms
Mr. S. R. Hughes	Mr. R. H. Whitby
Mr. T. V. Somerville	Mr. A. H. Yates

Fuels and Oils Committee

Mr. E. L. Bass (*Chairman*)	Mr. F. L. Garton
Mr. A. E. Bingham	Mr. C. D. Holland
Professor F. H. Garner	Mr. G. Morris

Fatigue Committee

Mr. H. L. Cox (*Chairman*)	Mr. H. B. Howard
Mr. R. J. Atkinson	Mr. N. H. Mason
Mr. G. Forrest	Mr. R. H. Sandifer
Mr. H. Giddings	Mr. W. Tye

The Technical Staff have, in addition to work with the Technical Committees, undertaken a number of assignments of a technical nature on behalf of the Society. In

particular, the organisation of the Joint Conference between the Society and the Institute of Physics (Stress Analysis Group) at Cranfield from 19th to 21st September 1956, the weekend Conference on Advanced Aeronautical Education at Cranfield on 23rd and 24th March and All-day Section Lectures and Discussions on Supersonic Flight and Transonic Wind Tunnel Testing Techniques was undertaken by the Technical Staff. Members of the Technical Staff have also acted as Observers on the Society's behalf at various meetings of other bodies.

For the purposes of publicity and to answer the many queries received on Data Sheets in general, a brochure has now been prepared and copies of this are obtainable upon application to the Secretary.

Mr. N. B. Joyce, seconded to the Society from the Aeronautical Research Laboratory, Fishermen's Bend, Melbourne, Australia, has now returned to Australia, having spent about twelve months working on Data Sheets.

Dr. E. W. C. Wilkins has left the Technical Staff and is now working with Lockheeds in California.

Garden Party

The Society's Garden Party was held at Wisley Aerodrome, by kind permission of Vickers-Armstrongs (Aircraft) Ltd. and the Ministry of Supply, on Sunday 15th July 1956. A full report was published in the October 1956 JOURNAL.

Donations

This report shows that the work of the Society continues to increase; much of this increase is made possible by generous donations from the Industry, the Ministry of Supply and the S.B.A.C. and to them all the Council wishes to record its thanks.

Donations have been received during 1956 from the following:

Bristol Aeroplane Company Limited
de Havilland Aircraft Company Limited
Dowty Equipment Limited
English Electric Group
Folland Aircraft Limited
Hawker Siddeley Group
Hunting Percival Aircraft Limited
Ministry of Supply
Rolls-Royce Limited
Society of British Aircraft Constructors
Vickers-Armstrongs Limited
Westland Aircraft Limited

The Society has also received grants from:

Society of British Aircraft Constructors
Ministry of Supply

for technical work.

Library

The work of the Library continues to expand and increase.

An interesting comparison can be made with the figures for 1950 which are given in brackets: Loans 1,149 (632), Acquisitions 337 (164), Review Copies 197 (50), Purchases 80 (80). It will be noticed that there are now almost four times as many review copies as previously. There are two contributing factors to this; an increasing appreciation by publishers of the authority of the JOURNAL'S reviews and the practice of requesting a review copy when it is thought that the book is likely to be of interest.

A big factor in the increase of loans (an increase of 144 over the previous highest figure) is the regular acquisition of the I.A.S. preprints.

The historical collection grows slowly but it received a notable impetus by the generosity of Mrs. John Bell who gave the Society first choice of her late husband's large library. There were many photographs and albums of photographs in the library and it will be some time before these are properly indexed. Other interesting material was presented by Messrs. H. F. Cowley (*Companion*), B. S. Shenstone (*Fellow*), A. N. Jackson (*Associate Fellow*), G. Dorman (*Associate*), J. Thirkettle (*Associate Fellow*), and T. D. Sills (*Associate Fellow*).

The Society has just learned that under the will of the late Mr. Alan de Mowbray Bellairs his collection of aeronautical prints has been bequeathed to the Society. He began his collection in 1909 when he first took up ballooning.

The Council deeply appreciates all these gifts.

Previous Library reports have commented on increases in telephone and letter inquiries. The increase persists. Over a period, some inquiries show a definite trend, making possible a certain amount of anticipation in what items of information to note.

One definite fact emerges. The Society is regarded as the first source for all matters of aeronautical history. It is, therefore, imperative that the Library should acquire and retain everything possible which is concerned with the past; members can help considerably in this.

Publications

THE JOURNAL has maintained its progress during the past year in spite of a substantial increase in printing costs; the number of copies printed had risen to 10,400 a month by March 1957. The increase is mainly due to the growing membership of the Society but outside subscriptions and sales of single copies are also increasing.

During the past twelve months more section lectures have been published and more papers have been received from the Branches; since January 1956 the Graduates' and Students' Section has been allotted a page each month and the amount of space devoted to the Library has increased, mainly because of the ever-increasing number of reports received and the additions to the Library. Although more books have been reviewed the number published on the aeronautical and allied sciences is increasing so rapidly that it is impossible to review them all adequately; because of this it is proposed this year to refer briefly only to those books on the allied sciences, or with only an indirect bearing on aeronautics, which are likely to be reviewed at length elsewhere; aeronautical books or those which have a direct bearing on aeronautics, and which are of greater importance to members, will be reviewed authoritatively and at greater length. It is hoped that this policy will reduce the delay in publishing reviews of new books.

From time to time members complain that certain aspects of aeronautics are not dealt with in the Journal; obviously it is impossible to cover the entire range without doubling the size of the Journal but more papers were published in 1956 and on many more aspects. Apart from lectures and a request sometimes to a member to write a paper on a specific subject, the Journal is dependent on the papers submitted for publication and, as the number of worthwhile papers received increases, so does the delay in publication. Delays in publishing technical notes, which for a time were averaging four or five months rather than the original two or three, may have been responsible for the drop in the number of technical notes received during the latter half of 1956; the situation is improving for the delay is yet less and the number of technical notes more.

The difficult question of wrappers and envelopes has continued to receive attention; both were used in 1956 and will be used again in 1957. Judging from infrequent comments received, overseas journals travel better when rolled, but home members prefer envelopes. Unfortunately costs, including increased postage, prohibit the use of the ideal protective covering.

A supplement to the 1955/56 Year Book, containing a list of new members, transfers of membership, resignations

and deaths, between 2nd September 1955 and 31st December 1956, was issued with the January 1957 JOURNAL.

The position of THE AERONAUTICAL QUARTERLY is now firmly established and the only concern is the difficulty of publishing, within a reasonable time, the large number of good papers received. This problem is being tackled and it is expected that, within the year, the time lag between receipt and publication of a paper will be less than a year. The standard of papers has risen; the field has widened, so that the balance between aerodynamics and other subjects is more even; in particular, there are far more structures papers than before. It has been agreed that in 1957 a limited number of advertisement pages be accepted in the form of "recruitment pages," where groups of firms can bring their activities to the notice of readers in the many fields of aeronautics and allied sciences covered by the Quarterly.

The Council wishes to record the invaluable work done by the referees in suggesting improvements to authors and in maintaining the high standard of the Quarterly.

The first of the Society's TEXTBOOKS was published early in 1957 and will be followed closely by two more. The first two volumes are on "Aircraft Hydraulics," by a panel of experts under the Editorship of Mr. H. G. Conway, and the third is "Landing Gear Design," written by Mr. Conway.

No new MONOGRAPHS were published during the year, but a volume by Mr. C. N. Jaques on aircraft instrumentation is in the Press. A book on aircraft electrics is almost complete in manuscript and plans are well under way for a comprehensive, classified fatigue bibliography. Sales of the four previous monographs are continuing.

Staff

There have been a considerable number of changes in the Staff of the Society. Miss Betty Voyce, after more than twenty-eight years on the Staff, resigned and in her place Mr. R. H. Levinson has been appointed as Accountant.

There have been considerable changes in the Secretarial Staff, for many have resigned on being married.

The Council has decided to create the office of an Education Officer to deal with the increasing educational activities of the Society.

Associate Fellowship Examination

The Associate Fellowship Examinations were held in June and December 1956, again under the old and new Syllabus. The number of candidates at home and abroad in June was 64 and the number in December was 90. The Examination was held in the following countries at the various Universities and Institutions. The Council wishes to thank them for their co-operation:—Australia, Canada, India, Italy, Pakistan, the U.S.A. and in B.A.O.R.

A list of those candidates who were successful in the June examinations was published in the September 1956 JOURNAL and the successful candidates in the December examinations were published in the March 1957 JOURNAL.

Obituaries

The Council regrets to record the death of the following Members of the Society:

C. A. Baker (*Associate*)
J. L. Batchelor (*Associate*)
J. W. Birkle (*Associate Fellow*)
Group Capt. W. G. Campbell (*Associate Fellow*)
D. W. L. Fairbank (*Associate Fellow*)
Sir Richard Fairey (*Fellow*)
J. D. Frier (*Fellow*)
Pilot Officer T. R. Fuller (*Graduate*)
L. D. Gardner (*Fellow*)
Major H. Hemming (*Fellow*)
D. M. Hudson (*Associate*)
G. H. Hurley (*Associate*)
C. Jones (*Associate*)
H. Judson (*Graduate*)
Sir W. J. Mallinson (*Founder Member*)
Commander F. W. Merriam (*Fellow*)
H. L. Milner (*Fellow*)
R. G. Prasad (*Graduate*)
F. B. Rentschler (*Associate Fellow*)
R. Reynolds (*Associate*)
F. Sigrist (*Fellow*)
J. P. Smith (*Student*)
Sir Keith Smith (*Fellow*) (Aust. Div.)
Air Vice-Marshal E. W. Stedman (*Fellow*)
Commander J. L. L. Taton (*Associate*)
P. J. Taylor (*Associate Fellow*)
O. Thornycroft (*Fellow*)
A. F. Walsh (*Associate Fellow*)
E. B. Wilshire (*Associate*) (Aust. Div.)

TECHNICAL NOTES

The "Ground" Interference of a Carrier Deck

by

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AN ESTIMATE is made of the "ground" interference effect of the deck of an aircraft carrier. It is shown that in the extreme case of wing span equal to deck width the induced upwash is of the order of 20 per cent less than the usual ground interference value. Thus the landing characteristics of an aircraft should not be markedly affected.

INTRODUCTION

It seems that there should be a difference between landing an aircraft on a stationary aircraft carrier and on the ground, due to modification of the ground-interference effect by the finite width of the carrier deck, particularly if for some reason large aircraft are to be used. In this note an estimate is made of the magnitude of this effect.

An examination of the literature[1, 2, 3, 4] indicates that the dominant lift interference terms arise from the upwash due to the images of the trailing vortices, and, for small heights and large lift coefficients, from the induced longitudinal velocity arising from the images of the bound vortices.

To determine the magnitude of the interference effect on the lift, the wing is represented by a lifting line and the carrier deck is represented by a plateau of width $2b$ at a height above sea level large compared with the height of the aircraft above the deck, so that the section made by a vertical plane through the lifting line appears as in Fig. 1(*b*). A great simplification is achieved if the lifting line is taken to be uniformly loaded and of length $2s$ equal to the wing span. This should be sufficient for the present purpose, although more sophisticated models could be used if necessary.

The effect of the bound vortices may be determined as follows. Since a finite line vortex induces no velocity in the direction of its axis, the vertical sides of the "deck" have no effect on the image of the lifting line (provided the span is less than the deck width) and the ground effect due to the bound vortex image is the same as that for an infinite deck width, *i.e.* the usual ground effect term.

The results show that even in the extreme case of the wing span equal to the deck width the change in the induced upwash from the usual value (for an infinite deck width) is of the order of 20 per cent at heights where the usual upwash is significant (*see* Fig. 3).

THEORY

For the purpose of the following computation the carrier deck is represented by a plateau of width $2b$, and the aircraft by a lifting line of length $2s$ symmetrically placed at height h above the deck. The plan view of the deck and the lifting line with its trailing vortex system is shown in Fig. 1(*a*) and the elevation in a vertical plane through the lifting line in Fig. 1(*b*). In this plane rectangular co-ordinates x, y are introduced so that x is the spanwise co-ordinate and y the vertical co-ordinate with origin at the centre of the deck. (Since h is assumed to be much less than the height of the deck above the sea, the sea is regarded to be at $y=-\infty$). At the point x of the lifting line the vorticity is $K(x)$ in the sense shown and between x and $x+dx$ an amount $-(dK/dx)\,dx$ is shed into the trailing vortex sheet.

In the complex $z\,(=x+iy)$-plane the lifting line is $z=x_0+ih$, $-s\leqslant x_0\leqslant s$, Fig. 2(*a*), and the flow in this plane due to the trailing vortices is the same as the two-dimensional flow due to point vortices distributed along the lifting line, such that between x_0+ih and x_0+dx_0+ih the vortex strength is $k(x_0)\,dx_0$ in the sense shown (when viewed from the front) where

$$k(x_0)=\tfrac{1}{2}\frac{dK}{dx_0}. \qquad (1)$$

Thus, in this plane, the flow field due to the trailing vortices in the presence of the deck may be solved by complex variable methods—in particular by mapping the exterior of the deck into a half-plane.

Although this case is apparently not covered by the normal Schwarz-Christoffel transformation, it may be verified that the region outside the "deck," $A\diagdown BCD\diagup$, is mapped into the upper half of the complex ζ-plane through the transformation

$$z=\frac{2b}{i\pi}\{\zeta(\zeta^2-1)^{\frac{1}{2}}-\log(\zeta+(\zeta^2-1)^{\frac{1}{2}})\}+h, \qquad (2)$$

where $(\zeta^2-1)^{\frac{1}{2}}$ is real and positive for ζ real and $\zeta>1$, and the logarithm takes its principal value. The correspondence is shown in Fig. 2.

A vortex of strength $k(x_0)\,dx_0$ at the point x_0+ih in the z-plane corresponds to a vortex of the same strength

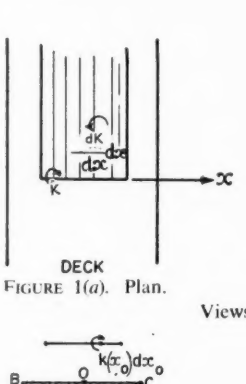

FIGURE 1(*a*). Plan.

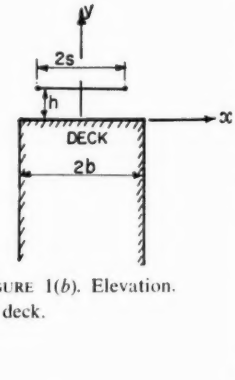

FIGURE 1(*b*). Elevation.

Views of the deck.

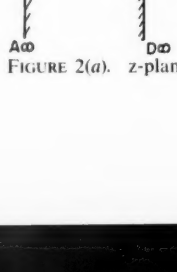

FIGURE 2(*a*). z-plane.

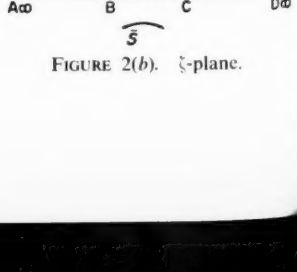

FIGURE 2(*b*). ζ-plane.

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on the curve S in the ζ-plane, where S is the map of $z=x_0+ih$, $-s\leqslant x_0\leqslant s$. Let σ be the element of arc length on S such that $\sigma=0$ when $\xi=0$. On $\bar{S}$, the image of S in the real axis, σ is the same function of x_0 as for S, so that if $z_0=x_0+ih$ maps into $\zeta_0=\xi_0+i\eta_0$ the complex potential in the ζ-plane for which the real axis is a streamline is

$$dW=\frac{ik\,(x_0)}{2\pi}\frac{dx_0}{d\sigma}\log(\zeta-\zeta_0)\,d\sigma-\frac{ik\,(x_0)}{2\pi}\frac{dx_0}{d\sigma}\log(\zeta-\bar{\zeta}_0)\,d\sigma$$

and the complex potential corresponding to the line of vortices is

$$W=\frac{i}{2\pi}\int_S k\,(x_0)\frac{dx_0}{d\sigma}\log(\zeta-\zeta_0)\,d\sigma-\frac{i}{2\pi}\int_{\bar{S}} k\,(x_0)\frac{dx_0}{d\sigma}\log(\zeta-\bar{\zeta}_0)\,d\sigma$$

$$=\frac{i}{2\pi}\int_{-s}^{s} k\,(x_0)\log[(\zeta-\zeta_0)/(\zeta-\bar{\zeta}_0)]\,dx_0. \quad . \quad . \quad (3)$$

where

$$x_0+ih=\frac{2b}{i\pi}\{\zeta_0(\zeta_0^2-1)^{\frac{1}{2}}-\log(\zeta_0+(\zeta_0^2-1)^{\frac{1}{2}})\}+b. \quad (5)$$

Since $$k\,(x_0)=\tfrac{1}{2}\frac{dK}{dx_0},$$

$$W=\frac{i}{4\pi}\int_{-s}^{s}\frac{dK}{dx_0}\log[(\zeta-\zeta_0)/(\zeta-\bar{\zeta}_0)]\,dx_0. \quad . \quad (4)$$

For uniform loading

$$K\,(x_0)=K_1\{H\,(x_0+s)+H\,(s-x_0)-1\}, \quad . \quad (5)$$

where $$H\,(x)=1,\ x>0,$$
$$H\,(x)=0,\ x<0. \quad . \quad . \quad . \quad (6)$$

Thus $$\frac{dK}{dx_0}=K_1\{\delta\,(x_0+s)-\delta\,(s-x_0)\} \quad . \quad . \quad (7)$$

where $\delta\,(x)$ is the Dirac δ-function, and

$$W=\frac{iK_1}{4\pi}\{\log[(\zeta-\zeta_0(-s))(\zeta-\bar{\zeta}_0(s))]-\log[(\zeta-\bar{\zeta}_0(-s))(\zeta-\zeta_0(s))]\}, \quad (8)$$

where it is assumed that in the integral in (4) the terminals are $-s-0$ and $s+0$. This potential has the correct form of singularity on $z=x+ih$ but could have added a function, W_1, *regular* in the finite upper half plane for which $\mathcal{I}dW_1/d\zeta=0$ on the real axis in the ζ-plane. But if dW/dz is required to be $0(z^{-1})$ for large $|z|$ then $dW_1/d\zeta$ must be $0(\zeta^{-1})$ for large $|z|$ and thus must vanish, see, for example, Ref. 5, p. 112.

Thus the form given by (8) is the correct potential in the z-plane and if u, v are the x and y velocity components,

$$\frac{dW}{dz}=u-iv=-\frac{K_1}{16b}(\zeta^2-1)^{-\frac{1}{2}}\{(\zeta-\zeta_0(-s))^{-1}-(\zeta-\bar{\zeta}_0(-s))^{-1}-(\zeta-\bar{\zeta}_0(s))^{-1}+(\zeta-\bar{\zeta}_0(s))^{-1}\}$$

since $$\frac{dz}{ds}=\frac{4b}{i\pi}(\zeta^2-1)^{\frac{1}{2}}.$$

By symmetry, if

$$\zeta_0(s)=s'+ih'$$

then $$\zeta_0(-s)=-s'+ih, \quad . \quad . \quad . \quad (9)$$

and therefore

$$\frac{dW}{dz}=-\frac{K_1}{16b}(\zeta^2-1)^{-\frac{1}{2}}\{(\zeta+s'-ih')^{-1}-(\zeta+s'+ih')^{-1}-(\zeta-s'-ih')^{-1}+(\zeta-s'+ih')^{-1}\}. \quad (10)$$

The potential due to the original vortices in the z-plane is

$$W_0=\frac{iK_1}{4\pi}\{\log(z+s-ih)-\log(z-s-ih)\}. \quad (11)$$

so that

$$\frac{dW_0}{dz}=\frac{iK_1}{4\pi}\{(z+s-ih)^{-1}-(z-s-ih)^{-1}\}$$

and

$$u'-iv'=-\frac{K_1}{16b}(\zeta^2-1)^{-\frac{1}{2}}\{(\zeta+s'-ih')^{-1}-(\zeta+s'+ih')^{-1}-(\zeta-s'-ih')^{-1}+(\zeta-s'+ih')^{-1}\}-\frac{iK_1}{4\pi}\{(z+s-ih)^{-1}-(z-s-ih)^{-1}\}, \quad (10)$$

where u', v' are the interference velocities due to the presence of the deck.

For the present purpose it is sufficient to find the upwash at the centre of the lifting line. Let

$$\zeta=iH \quad . \quad . \quad . \quad (10)$$

when $$z=ih,$$

then

$$v'(z=ih)=\frac{K_1}{2\pi s}-\frac{K_1 s}{8b}(1+H^2)^{-\frac{1}{2}}\{[s'^2+(H-h')^2]^{-1}-[s'^2+(H+h')^2]^{-1}\}. \quad (11)$$

Now by definition

$$\frac{K_1}{V}=\frac{SC_L}{4s}=\frac{C_L s}{A}, \quad . \quad . \quad (12)$$

where S is the wing plan form area, C_L is the lift coefficient and A is the aspect ratio. Thus for a constant C_L the increase in the angle of incidence is given by

$$\Delta\alpha=-\frac{v'}{V}(z=ih)=-\frac{C_L}{A\pi}\Sigma \quad . \quad . \quad (13)$$

where

$$\Sigma=\tfrac{1}{2}\left\{1-\frac{\pi s s' H h'}{b(1+H^2)^{\frac{1}{2}}[s'^2+(H-h')^2)(s'^2+(H+h')^2)]}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

The relations between s', h', H, s/b and h/b are simplified by the introduction of the auxiliary parameters α, β, γ where

$$\left.\begin{aligned}s'&=\cosh\alpha\cos\beta\\ h'&=\sinh\alpha\sin\beta\end{aligned}\right\},\ \beta_0\leqslant\beta<\pi/2, \quad . \quad (15)$$

$$H=\sinh\gamma$$

and $$\sin 2\beta_0=2\beta_0-\pi(1-s/b). \quad . \quad . \quad (16)$$

Then $$\frac{s}{b}=\frac{2}{\pi}\{\tfrac{1}{2}\cosh 2\alpha\sin 2\beta+\tfrac{1}{2}\pi-\beta\}, \quad . \quad 16(a)$$

$$\frac{h}{b}=\frac{2}{\pi}\{\alpha-\tfrac{1}{2}\sinh 2\alpha\cos 2\beta\}, \quad . \quad . \quad 16(b)$$

$$=\frac{2}{\pi}\{\gamma+\tfrac{1}{2}\sinh 2\gamma\}. \quad . \quad . \quad . \quad 16(c)$$

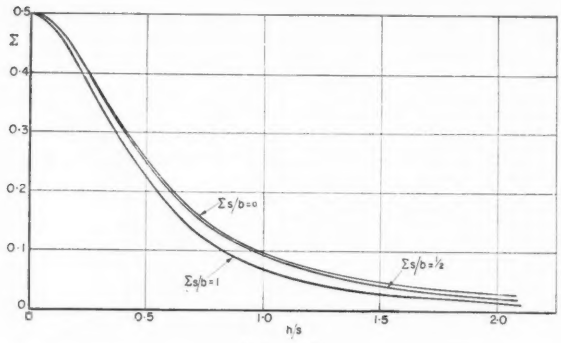

FIGURE 3.

$$\Delta\alpha = -\frac{C_L}{A\pi}\Sigma$$

When $b \longrightarrow \infty$, the ordinary case, $\beta \longrightarrow \frac{1}{2}\pi$ and $\alpha \longrightarrow 0$, so that

$$\frac{s}{b} \simeq \frac{4}{\pi}\left(\frac{\pi}{2} - \beta\right),$$

$$\frac{h}{b} \simeq \frac{4}{\pi}\alpha,$$

and hence

$$s' \simeq \frac{\pi}{4}\frac{s}{b}, \quad h' \simeq \frac{\pi}{4}\frac{h}{b}, \quad H \simeq \frac{\pi}{4}\frac{h}{b},$$

and

$$\Sigma \longrightarrow \Sigma_0 = \tfrac{1}{2}\frac{s^2}{s^2 + 4h^2}. \qquad (17)$$

Thus $\Sigma_0 = 0\,[(h/s)^{-2}]$ for h/s large while it may be shown that $\Sigma = 0\,[(h/s)^{-3}]$ when b is finite, so that the ground effect dies away more quickly for a "finite" ground, as could be expected.

RESULTS

Values of Σ for $s/b = \frac{1}{2}$ and $s/b = 1$ have been computed for various heights, starting with the relation 16(*a*) in the form

$$\cosh 2\alpha = [2\beta - \pi(1 - s/b)] \Big/ [\sin 2\beta].$$

These are compared with Σ_0 in Table I and in graphical form in Fig. 3.

TABLE I

h/s	$\Sigma s/b=1$	$\Sigma s/b=1/2$	Σ_0
0·0052	0·4999	0·4999$_5$	0·4999$_5$
0·0419	0·4945	0·4965	0·4965
0·1424	0·4529	0·4623	0·4625
0·3450	0·3163	0·3379	0·3388
0·5377		0·2300	0·2319
0·7131	0·1335	0·1619	0·1648
1·0020	0·0699	0·0921	0·0969
1·4179	0·0309	0·0491	0·0553
1·7797		0·0296	0·0366
2·0809	0·0106	0·0201	0·0273

With typical modern aircraft, the minimum value of h/s (at touchdown) probably lies in the range 0·3 to 0·6 and it is seen that the percentage difference between Σ and Σ_0 is not very great until Σ is quite small, *i.e.* when h/s is greater than about unity. It would seem that the differences found here would normally have a negligible effect.

ACKNOWLEDGMENT

Acknowledgment is made by the author to the Chief Scientist, Department of Supply, Australia, for permission to publish this note.

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*Thickness Parameters by Rapid Integration of Turbulent Boundary Layer Profiles**

by

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THE TURBULENT boundary layer on an aerofoil is represented by simple distributions of velocity, so as to obtain approximate general formulae for the displacement and momentum thicknesses in terms of two ratios of local velocity to that at the edge of the boundary layer. Optimum positions for the local velocity are calculated to be at 0·15 and 0·62 of the boundary layer thickness from the aerofoil surface. The accuracy of the formulae is closely examined. A rapid experimental and numerical procedure is given for estimating the displacement and momentum thicknesses within ±2 per cent. A minimum of seven velocity measurements has been found satisfactory in practice.

Received 30th November 1956

*The work described in this Note was carried out in the Aerodynamics Division of the National Physical Laboratory, and it is published on the recommendation of the Aeronautical Research Council and by permission of the Director of the Laboratory.

INTRODUCTION

When boundary layers on aerofoils are explored, measurements of velocity very close to the aerofoil surface

cannot be trusted. Whether a calibrated probe or a total-head tube is used, the measurements will be influenced by the velocity gradient normal to the aerofoil and also by the interference between the instrument and the aerofoil. Both effects will become large and generally unpredictable as the instrument approaches the surface. When a turbulent boundary layer is fairly thin, the reliable measurement nearest to the surface may well be $u=0{\cdot}6U$, when $z=0{\cdot}1\delta$, so that it is troublesome to decide how sharply the velocity u falls to zero at the surface. When the innermost tenth of the boundary layer is uncharted, the evaluation of the integrals

$$\left.\begin{aligned}\delta_1 &= \int_0^{\delta}\left(1-\frac{u}{U}\right)dz\\ \delta_2 &= \int_0^{\delta}\frac{u}{U}\left(1-\frac{u}{U}\right)dz\end{aligned}\right\} \quad . \quad . \quad (1)$$

for the displacement and momentum thicknesses presents difficulty: the region $0<z<0{\cdot}1\delta$ may contribute as much as 30 per cent of δ_1 and 20 per cent of δ_2. The following method is devised to compute these parameters in such a case to a probable accuracy of ± 1 per cent. The resulting formulae are so simple that they may be found useful whenever a rapid integration of turbulent profiles is required.

DERIVATION OF FORMULAE

The velocity profile is taken to be

$$u/U=\zeta^t(a_0+a_1\zeta+a_2\zeta^2+a_3\zeta^3), \quad . \quad . \quad (2)$$

where $\zeta=z/\delta$, $a_0+a_1+a_2+a_3=1$ and t is to be chosen.

Then from (1) and (2)

$$\frac{\delta_1}{\delta}=1-\frac{a_0}{1+t}-\frac{a_1}{2+t}-\frac{a_2}{3+t}-\frac{a_3}{4+t}. \quad . \quad (3)$$

An increment

$$\Delta_1(u/U)=\zeta^t(\zeta_1-\zeta)(\zeta_2-\zeta)(1-\zeta) \quad . \quad (4)$$

to the velocity profile will leave δ_1 unaltered, if

$$-\frac{X}{1+t}+\frac{X+Y}{2+t}-\frac{Y+1}{3+t}+\frac{1}{4+t}=0$$

or $$(3+t)(4+t)X-(1+t)(4+t)Y+(1+t)(2+t)=0, \quad (5)$$

where

$$\left.\begin{aligned}X&=\zeta_1\zeta_2\\ Y&=\zeta_1+\zeta_2\end{aligned}\right\}.$$

In so far as (2) may represent the velocity profile, it is valid to write

$$(u/U)^2=\zeta^{2t}(b_0+b_1\zeta+b_2\zeta^2+b_3\zeta^3), \quad . \quad (6)$$

where $b_0+b_1+b_2+b_3=1$.

Then from (1) and (6)

$$\frac{\delta_1}{\delta}+\frac{\delta_2}{\delta}=1-\frac{b_0}{1+2t}-\frac{b_1}{2+2t}-\frac{b_2}{3+2t}-\frac{b_3}{4+2t}. \quad (7)$$

An increment

$$\Delta_2(u/U)^2=\zeta^{2t}(\zeta_1-\zeta)(\zeta_2-\zeta)(1-\zeta) \quad . \quad (8)$$

to (6) will leave $(\delta_1+\delta_2)$ unaltered, if

$$(3+2t)(4+2t)X-(1+2t)(4+2t)Y+(1+2t)(2+2t)=0. \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Conditions (5) and (9) lead to

$$\left.\begin{aligned}X=\quad \zeta_1\zeta_2&=\frac{(1+t)(1+2t)}{(4+t)(4+2t)}\\ Y=\zeta_1+\zeta_2&=\frac{(1+t)(11+4t)}{(4+t)(4+2t)}\end{aligned}\right\},$$

so that ζ_1 and ζ_2 are the roots of the equation

$$(4+t)(4+2t)\zeta^2-(1+t)(11+4t)\zeta+(1+t)(1+2t)=0,$$

whence

$$\zeta=\frac{(1+t)(11+4t)\pm\{(1+t)(57+33t)\}^{\frac{1}{2}}}{4(4+t)(2+t)}. \quad (10)$$

When these values of ζ_1 and ζ_2 are considered in (4) and (8), it becomes clear that, subject to the validity of (2) and (6), δ_1/δ in (3) and $(\delta_1+\delta_2)/\delta$ in (7) are expressible in terms of the velocities u_1 and u_2 at these two positions. The coefficients a_0, a_1, a_2, a_3 and b_0, b_1, b_2, b_3 are eliminated to give

$$\frac{\delta_1}{\delta}=\frac{t}{1+t}+\frac{1}{(2+t)(3+t)(4+t)(\zeta_2-\zeta_1)}\left[\frac{\zeta_2(4+t)-(2+t)}{\zeta_1(1-\zeta_1)}\left\{1-\frac{u_1}{U}\zeta_1^{-t}\right\}+\frac{(2+t)-\zeta_1(4+t)}{\zeta_2(1-\zeta_2)}\left\{1-\frac{u_2}{U}\zeta_2^{-t}\right\}\right] \quad (11)$$

and $(\delta_1+\delta_2)/\delta$ equal to an identical expression with t replaced by $2t$ throughout and u_1/U, u_2/U replaced by $(u_1/U)^2$, $(u_2/U)^2$ respectively. The final result is then

$$\frac{\delta_1}{\delta}=A_0-A_1\frac{u_1}{U}-A_2\frac{u_2}{U}, \quad . \quad . \quad . \quad (12)$$

$$\frac{\delta_2}{\delta}=B_0-B_1\left(\frac{u_1}{U}\right)^2-B_2\left(\frac{u_2}{U}\right)^2-\frac{\delta_1}{\delta}, \quad (13)$$

where A_0, A_1, A_2, B_0, B_1, B_2 are functions of t, and u_1, u_2 are the values of $u(\zeta)$ when $\zeta=\zeta_1$, ζ_2. A few calculated values are given below:

TABLE I

t	ζ_1	ζ_2	A_0	A_1	A_2	B_0	B_1	B_2
0·15	0·1373	0·6103	0·8733	0·3273	0·5382	0·8737	0·3217	0·5400
0·20	0·1468	0·6195	0·8769	0·3370	0·5289	0·8774	0·3302	0·5310
0·25	0·1560	0·6283	0·8803	0·3459	0·5200	0·8809	0·3383	0·5223
0·30	0·1652	0·6366	0·8836	0·3540	0·5114	0·8843	0·3458	0·5138

ACCURACY OF FORMULAE

The next step is to consider how the formulae (12) and (13) compare with accurately integrated turbulent boundary layers. The best choice of t must be expected to depend on the velocity profile. In terms of the shape parameter $H=\delta_1/\delta_2$, a power-law profile gives

$$\left.\begin{aligned}u/U&=\zeta^{1/(H-1)}\\ \delta_1/\delta&=(H-1)/(H+1)\\ \delta_2/\delta&=(H-1)/H(H+1)\end{aligned}\right\} \quad . \quad . \quad (14)$$

Identical results follow from the formulae when $t=\frac{1}{2}(H-1)$. When the profile (14) is substituted in equation (12), it is found that throughout the range $1{\cdot}\dot{3}\leqslant H\leqslant 3$ the value of δ_1/δ with $t=0{\cdot}20$ lies within $\pm 0{\cdot}7$ per cent of the exact value. For any other value of t, larger numerical percentage errors in the calculated δ_1 occur for some value of H in the given range. When the profile is substituted in equation (13) with $t=0{\cdot}20$, the value of $(\delta_1+\delta_2)/\delta$ is obtained within $\pm 0{\cdot}25$ per cent of

the exact value $(H-1)/H$ from (14) throughout the range $1\dot{3} \leqslant H \leqslant 3$. This suggests that $t=0{\cdot}20$ is the best choice; it also points to a weakness in the proposed formulae, that δ_1 and δ_2 are liable to errors of opposite sign so that their ratio H becomes a crucial parameter. As a guide to accuracy, the percentage errors in evaluating $H=\delta_1/\delta_2$ from formulae (12) and (13) for power-law profiles are tabulated below for four values of t:

TABLE II

	Percentage error when exact H =						
t	$1\dot{3}$	1·4	1·5	$1\dot{6}$	2·0	2·5	3·0
0·15	−0·3	−0·9	$-1{\cdot}4_5$	$-1{\cdot}9_5$	−1·6	−0·6	$-0{\cdot}0_5$
0·20	+1·0	0	−0·9	−1·6	−1·6	−0·7	−0·1
0·25	+2·6	$+1{\cdot}3_3$	0	$-1{\cdot}1_5$	$-1{\cdot}5_3$	$-0{\cdot}8_5$	−0·2
0·30	+4·6	+2·8	+1·0	−0·6	−1·5	−1·0	−0·3

From Table II it seems that the choice of t is critical when H is low but matters little when H is high. Good accuracy for the highest value of H might be expected, because the velocities in the region $0<z<0{\cdot}1\delta$ are small and there is little scope for error in taking the velocity profile in (2). For most purposes an accuracy of about $\pm 1{\cdot}5$ per cent in H is sufficient, so that the formulae (12) and (13) with $t=0{\cdot}20$ are likely to be useful.

Especially for the large values of H, experimental profiles will be poorly represented by the power law. Selected velocity profiles from Fig. 10 of Ref. 1 are used to investigate the effect of profile shape. Four curves, nominally $H=1{\cdot}286$, 1·5, 1·8, 2·2, are reproduced in Fig. 1, integrated numerically to give δ_1/δ and δ_2/δ, and used to evaluate formulae (12) and (13) for $t=0{\cdot}15$, 0·20, 0·25, 0·30. All these calculated values are set out in Table III. Further evidence as to the best choice of t is provided by measured profiles of thick boundary layers, for which the integrals (1) can be evaluated reliably. Three such examples have been taken from Figs. 5, 7, 8 of Ref. 2. These results, together with those in Fig. 1, are analysed as follows:

The last column of Table IV confirms the accuracy deduced from Table II. From Table I and equations (12) and (13), the recommended formulae with $t=0{\cdot}20$ are

$$\left.\begin{aligned}\frac{\delta_1}{\delta} &= 0{\cdot}8769 - 0{\cdot}3370\frac{u_1}{U} - 0{\cdot}5289\frac{u_2}{U}\\ \frac{\delta_2}{\delta} &= 0{\cdot}8774_5 - 0{\cdot}3302\left(\frac{u_1}{U}\right)^2 - 0{\cdot}5310\left(\frac{u_2}{U}\right)^2 \dot{-} \frac{\delta_1}{\delta}\end{aligned}\right\}, \quad (15)$$

where u_1, u_2 are the values of u when $\zeta=0{\cdot}1468$, 0·6195 respectively. These formulae should normally be accurate

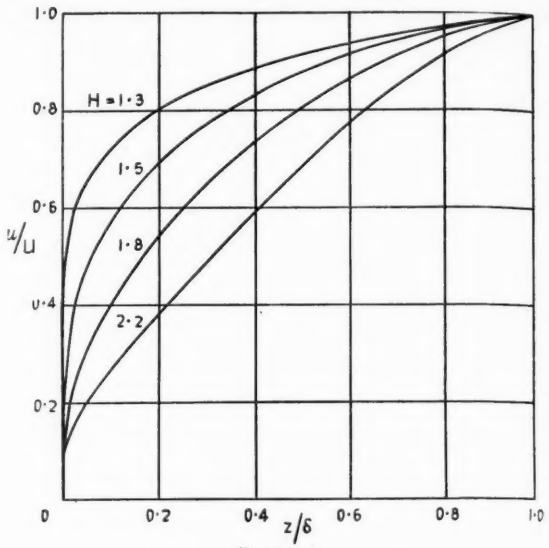

FIGURE 1.

TABLE III

H	*Integrated* δ_1/δ	*Value of* δ_1/δ *from formula (12) with* $t=0{\cdot}15$	$t=0{\cdot}20$	$t=0{\cdot}25$	$t=0{\cdot}30$
1·3	0·1195	0·1184	0·1201	0·1218	0·1238
1·5	0·1775	0·1760	0·1766	0·1775	0·1785
1·8	0·2554	0·2537	0·2541	0·2544	0·2548
2·2	0·3541	0·3519	0·3518	0·3521	0·3525

H	*Integrated* δ_2/δ	*Value of* δ_2/δ *from formula (13) with* $t=0{\cdot}15$	$t=0{\cdot}20$	$t=0{\cdot}25$	$t=0{\cdot}30$
1·3	0·0913	0·0918	0·0916	0·0911	0·0904
1·5	0·1169	0·1184	0·1181	0·1175	0·1167
1·8	0·1414	0·1429	0·1429	0·1426	0·1422
2·2	0·1621	0·1615	0·1610	0·1607	0·1603

to about ± 1 per cent. From the nine cases considered in a recent investigation at the National Physical Laboratory and given in Tables I-III of Ref. 3, the root mean square errors in formulae (15) are found to be $0{\cdot}7_5$ per cent for δ_1 and 0·6 per cent for δ_2; the root mean square error in $H=\delta_1/\delta_2$ is 0·7 per cent. It should be noticed that such errors are equivalent to changes of 0·003 in u_1/U or 0·002 in u_2/U, *i.e.* approximately 0·004 in $(u_1/U)^2$ or $(u_2/U)^2$.

TABLE IV

Boundary layer			*Integrated value of*			*Best choice of t for*			$t=0{\cdot}20$
Ref.	*Fig.*	*Profile*	δ_1/δ	δ_2/δ	H	δ_1/δ	δ_2/δ	H	*Percentage error in H*
2	5	$X=10{\cdot}5$ ft.	0·1381	0·1011	1·366	0·20	0·18	$0{\cdot}19_5$	$+0{\cdot}2_5$
2	7	$X=10{\cdot}5$ ft.	0·1443	0·1063	1·357	0·13	0·10	0·17	+0·8
2	8	$X=10{\cdot}5$ ft.	0·1032	0·0798	1·293	0·16	?	0·18	$+0{\cdot}7_5$
1	10	$H=1{\cdot}286$	0·1195	0·0913	1·309	$0{\cdot}18_5$	$0{\cdot}22_5$	$0{\cdot}19_5$	$+0{\cdot}1_5$
1	10	$H=1{\cdot}5$	0·1775	0·1169	1·519	0·25	0·29	0·27	$-1{\cdot}5_5$
1	10	$H=1{\cdot}8$	0·2554	0·1414	1·806	0·36	0·39	0·38	$-1{\cdot}5_5$
1	10	$H=2{\cdot}2$	0·3541	0·1621	2·184	?	0·10	0·19	$+0{\cdot}0_5$

CONCLUDING REMARKS

Now consider how (15) will be used in practice. All that is required is a smooth curve of the dynamic pressure q against z. It is best to work from a detailed traverse in the range $0{\cdot}1\delta < z < 1{\cdot}3\delta$. The value $q=Q$ at the edge of the boundary layer is easily estimated, but there may be latitude in the choice of δ. The general shape of the distribution of $q/Q=(u/U)^2$ in (6) should be borne in mind; the curve of q against z should be drawn with a decisive kink at the edge of the boundary layer, so as not to overestimate δ. Fortunately the formulae (15) are not particularly sensitive to the choice of δ; for a given curve $q(z)$ in the range $0{\cdot}1\delta < z < 0{\cdot}7\delta$, an increase of 5 per cent in the chosen value of δ will increase the calculated δ_1 and δ_2 by only about 0·7 and 1·0 per cent respectively. Then three readings from the curve, $q=q_1$, q_2, Q, when $z=0{\cdot}1468\delta$, $0{\cdot}6195\delta$, δ, readily determine

$$\left.\begin{aligned}\delta_1 &= \delta\,[0{\cdot}8769 - 0{\cdot}3370\sqrt{(q_1/Q)} - 0{\cdot}5289\sqrt{(q_2/Q)}]\\ \delta_2 &= \delta\,[0{\cdot}8774_5 - 0{\cdot}3302\,(q_1/Q) - 0{\cdot}5310\,(q_2/Q)] - \delta_1\end{aligned}\right\} \quad (16)$$

A rapid procedure for estimating δ_1 and δ_2 within ± 2 per cent is

(*i*) to traverse a velocity-measuring probe quickly and estimate Z, say, within ± 5 per cent of the correct δ;

(*ii*) to traverse the probe carefully and obtain accurate values of q at positions $z=0{\cdot}13Z$, $0{\cdot}16Z$, $0{\cdot}59Z$, $0{\cdot}65Z$, $0{\cdot}90Z$, $1{\cdot}00Z$, $1{\cdot}10Z$;

(*iii*) to graph q against z, to deduce δ and hence $z_1=0{\cdot}1468\delta$, $z_2=0{\cdot}6195\delta$, and the respective values $q=Q$, q_1, q_2;

(*iv*) to evaluate δ_1 and δ_2 from (16).

The minimum of seven measurements has been found satisfactory in practice, but it is emphasised that the graph of q is required to an accuracy of about $\pm 0{\cdot}005Q$.

By considering an extra term in (2) and (6) and by placing an extra factor $(\zeta_3-\zeta)$ on the right-hand sides of (4) and (8), it is easily shown that the displacement, momentum and energy thicknesses are all invariant if ζ_1, ζ_2, ζ_3 are the roots of the cubic equation

$$(5+t)(5+2t)(5+3t)\zeta^3 - (1+t)(131+103t+18t^2)\zeta^2 + \\ + (1+t)(31+59t+18t^2)\zeta - (1+t)(1+2t)(1+3t) = 0. \quad (17)$$

Hence a generalisation of the formulae (12) and (13) with one extra term is achieved. But there is little point in carrying this through, since ζ_1, ζ_2, ζ_3 are approximately 0·07, 0·34, 0·75, and ζ_1 is so small that it would normally be impracticable to measure u_1 with a pressure probe.

ACKNOWLEDGMENT

The author wishes to acknowledge the help of Miss S. M. Passmore, who did much of the computation.

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Slow Viscous Flow Within Circular Cylinders

by

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(Royal Aircraft Establishment)

AN EXACT solution of the streamlines of the slow viscous motion inside a cylinder with partially moving walls has been obtained and verified experimentally. This problem has been treated by H. B. Squire[1] for high Reynolds numbers.

NOTATION

ψ	stream function
ω	angular velocity
ν	kinematic viscosity
a	cylinder radius
$R=\omega a^2/\nu$	Reynolds number

The flow is generated inside the coaxial cylinders of radius a as shown in Fig. 1. The outer cylinder rotates at a constant angular velocity ω, so that $\omega a^2/\nu \leqslant 1$ and the equation of slow viscous motion is thus applicable. The inner cylinder is fixed and the solution is obtained in terms of the ratio of the length of moving arc to the circumference.

The equation of slow viscous motion is:

$$\nabla^4\psi = 0 \quad . \quad . \quad . \quad . \quad (1)$$

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where ψ is the two-dimensional stream function. A solution satisfying equation (1) and the boundary condition $\psi\,(a)=0$ is:[2]

$$\psi\,(r,\theta) = \omega a^2 \sum_0^\infty A_n\,[(r/a)^n - (r/a)^{n+2}]\,(\cos n\theta + b_n \sin n\theta). \quad (2)$$

Now the circumferential velocity v is given by:

$$v = -\left(\frac{\partial\psi}{\partial r}\right)_{r=a} = \omega a \sum_0^\infty 2A_n\,(\cos n\theta + b_n \sin n\theta)\,. \quad (3)$$

The boundary conditions at $r=a$ are that the fluid adheres to the fixed and rotating segments.

$$\alpha < \theta < 2\pi - \alpha \qquad v = \omega a \quad . \quad . \quad (4)$$

$$-\alpha < \theta < \alpha \qquad v = 0 \quad . \quad . \quad (5)$$

The correct viscous boundary conditions are thus satisfied and by comparing the Fourier series given by equations (4) and (5) with equation (3) it is found that:

$$b_n = 0$$

$$A_n = 1/\pi_n\,.\,\sin n\alpha \quad . \quad . \quad . \quad (6)$$

and $$A_0 = \alpha/2\pi$$

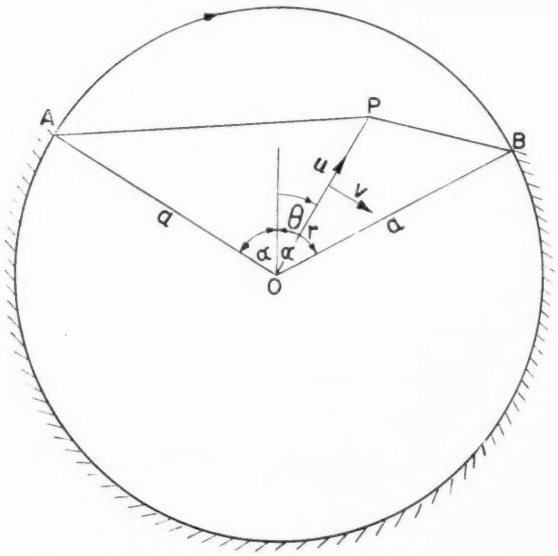

FIGURE 1. Co-ordinate system for cylindrical cavities.

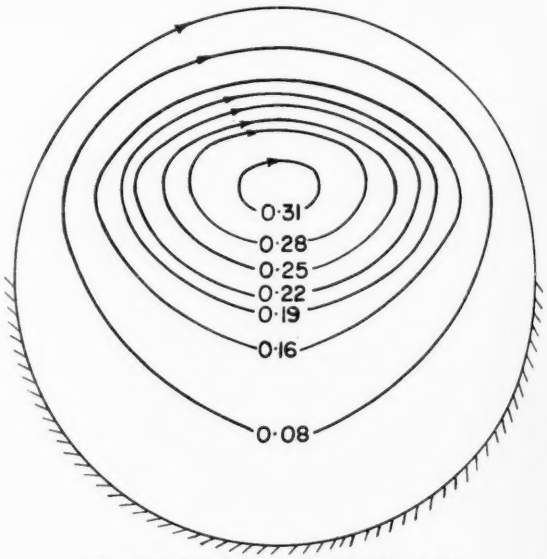

FIGURE 2. Streamlines of motion for $\alpha=90^\circ$. Lines are $\psi/\omega a^2=$constant.

It may be shown by complex series expansion of equations (2) and (6) (given in the Appendix) that:

$$\psi(r,\theta)=\frac{\omega a^2}{2\pi}[1-r^2/a^2]\left(\alpha-\tan^{-1}\frac{(r/a)^2\sin 2\alpha-2(r/a)\sin\alpha\cos\theta}{1-2(r/a)\cos\alpha\cos\theta+(r/a)^2\cos 2\alpha}\right) \quad (7)$$

and from the geometry of Fig. 1 the value of the stream function at the point P becomes

$$\psi_P=\frac{\omega a^2}{2\pi}[1-r^2/a^2](\alpha\pm\{\text{The sum of the angles OAP, OBP}\} \quad (8)$$

The positive sign is taken when $-\alpha<\theta<\alpha$ and the negative sign when $\alpha<\theta<2\pi-\alpha$.

The theoretical streamlines of the motion for the case $\alpha/\pi=\frac{1}{2}$ are shown in Fig. 2 and the variation of the eddy centre with α/π in Fig. 3. When $\alpha/\pi=1$ the complete circumference is in motion and hence the centre of the eddy is at the centre of the cylinders, the whole body of fluid rotating with an angular velocity ω. When $\alpha/\pi\longrightarrow 0$ there is only one point on the circumference in motion so that the centre of the limiting eddy must be at a, 0, and there is then no motion within the cylinders.

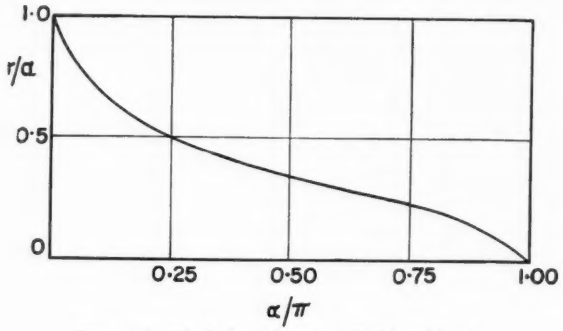

FIGURE 3. Variation of centre of eddy with α/π.

Some experiments were made by the author[3] at Brown University to verify this solution for the special case $\alpha/\pi=\frac{1}{2}$. The streamlines of the motion were made visible by aluminium particles scattered on the surface and a plate camera with its axis aligned with that of the cylinders was used to photograph the motion.

Figure 4 is a three second exposure of an eddy in glycerine. The white spots are particles which have fallen on to the reflector at the bottom of the cylinders and are out of focus. The white lines are the painted lips of the fixed cylinder.

The displacement of the eddy centre measured from this photograph is $0{\cdot}42a$, compared with the theoretical value of $0{\cdot}35a$. Since the wall thickness of the inner cylinder is $0{\cdot}05a$, a difference of this magnitude is not surprising. Fig. 5 gives a fifteen second exposure of the same eddy. The regularity of the streamlines near the singular points of the mathematical solution should be noted at the corner B in Fig. 4 and at the corner A in Fig. 5.

Unfortunately the flash light illuminating the apparatus altered the temperature of the glycerine and lowered its viscosity. Temperature measurements during the experiment showed that:

$$2<R=\omega a^2/\nu<9.$$

This variation of Reynolds number was eliminated by observing an eddy in silicon oil, for which $R=17$. The streamline photograph was like that of Fig. 5 but the centre of the eddy was displaced $0{\cdot}40a$. This is still fair agreement with the slow viscous motion theory, which predicts that the streamlines for both motions should be the same, when the Reynolds number is less than one.

In the final experiment an eddy was formed in water at a constant Reynolds number of $1{\cdot}6\times10^5$, *i.e.* a Reynolds number likely to be attained in aircraft cavities. The flow is now, of course, completely different from that given by the equation of slow viscous motion. Fig. 6 shows that the streamlines are nearly circular, which implies that the bulk of the fluid rotates as a solid body about an axis displaced $0{\cdot}10a$ away from the fixed cylinder. (The sense

FIGURE 4. Eddy in glycerine. Exposure 3 seconds.

FIGURE 6. Eddy in water. $R = 1{\cdot}6 \times 10^5$.

FIGURE 5. Eddy in glycerine. Exposure 15 seconds.

of this displacement is still away from the fixed cylinder.) Nothing can be learnt from this photograph of the boundary layer flow at the corners A and B. This photograph confirms the solution given by H. B. Squire[1] for the flow at high Reynolds numbers.

APPENDIX

From equations (2) and (6)

$$\psi(r,\theta) = \frac{\omega a^2}{2\pi}\left[1 - r^2/a^2\right]\left(\alpha + 2\sum_1^\infty (r/a)^n \frac{\sin n\alpha \cos n\theta}{n}\right).$$

Now

$$F = 2\sum_1^\infty (r/a)^n \frac{\sin n\alpha \cos n\theta}{n} =$$

$$= \mathcal{I}\sum_1^\infty \frac{1}{n}\left[\{r/a \,.\, e^{i(\alpha+\theta)}\}^n + \{r/a \,.\, e^{i(\alpha-\theta)}\}^n\right]$$

$$= -\mathcal{I}\ln\{1 - r/a \,.\, e^{i(\alpha+\theta)}\}\{1 - r/a \,.\, e^{i(\alpha-\theta)}\}$$

since $\sum_1^\infty \frac{x^n}{n} = -\ln(1-x)$.

Therefore

$$F = -\mathcal{I}\ln\{1 - r/a \,.\, e^{i\alpha}\, 2\cos\theta + (r/a)^2 e^{2i\alpha}\}$$

$$= -\tan^{-1}\frac{(r/a)^2 \sin 2\alpha - 2(r/a)\sin\alpha\cos\theta}{1 - 2(r/a)\cos\alpha\cos\theta + (r/a)^2\cos 2\alpha}$$

Equation (7) then follows.

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A Short-Cut Method for Estimating Aircraft Direct Operating Costs

by

E. N. BRAILSFORD

(*Bristol Aircraft Ltd.*)

MR. ROBERTSON'S method (January 1957 JOURNAL, p. 52) is most commendable in that it provides quick if approximate answers to cost queries.

Having had occasion to use it in parallel with more exact methods I find that it is optimistic. The reasons are not hard to find:—

(*i*) Costs other than the fuel costs are dependent upon block speeds and not cruise speeds. Block speeds can be approximated from given data if, as an example, it is assumed that ground time is 20 mins., and climb and descent time is 40 mins.

(*ii*) Fuel costs are related to sector distance which is much less than the equivalent still-air distance assumed in the method. Again approximate corrections can be suggested. Stand-off fuel may be allowed for by debiting from the E.S.A. distance, say one hour's distance at cruising speed. Reserves and allowances will account for an amount which will be not less than 5 per cent of remaining fuel, and will be nearer 10 per cent. It is suggested that the E.S.A. distance should be further reduced by this 10 per cent. The remaining distance is the sector plus diversion distance. Assuming 200 n. miles diversion gives the sector distance to use with the fuel costs.

(*iii*) As pointed out by Mr. C. J. H. Thomas in the March JOURNAL no allowance is made for crew costs.

For crew costs an additional term (1160 Cc/VP) may be added to the cost equation, where:—

Annual crew utilisation = 700 hrs./annum
Cc = £5,400 for 3 crew medium haul aircraft
= £7,300 for 5 crew medium haul aircraft
= £12,800 for 5 crew long haul aircraft
= £15,300 for 7 crew long haul aircraft.

Modifications of the type indicated above result in costs which are in reasonable agreement with those obtained by more exact and more tedious methods, providing the coefficients in the expression are corrected for any changes in load factor, utilisation, fuel-cost, and so on.

Received 19th March 1957.

Some Maintenance Aspects of Viscount Operation

by

E. R. MAJOR

IN CONNECTION with my paper which appeared in the September 1956 JOURNAL, my attention has been drawn to the possibility that Fig. 19 on page 616 could be misconstrued as indicating, in the case of the Elizabethan, that the two components shown on the right hand side of the diagram had very high defect rates. This was not the intention: the aim was to *compare* defect rates for similar or identical components fitted to both Viscount and Elizabethan aircraft with a view to showing that, in the main, identical components performed very similarly in both aircraft. As was stated at the time, this was taken as an indication that vibration was far from being the only, or even the most serious, factor in the causation of defects. It was unfortunate that one of the two components shown as having a high *relative* defect rate on the Elizabethan was described by name as a Plessey actuator. This was partially due to the two words jointly having become common usage, and also to the fact that the components used on the Elizabethan and Viscount, although virtually identical, were in fact used in entirely different applications. (This point was made in the text on page 614.)

However, to avoid any suggestion of implied criticism of Plessey products, it should be stated that although the relative defect rate on the Elizabethan was high, this was brought about by the Viscount rate being exceptionally low; consequently, although the Elizabethan rate was over eight times as great, it was still well below the average for this type of equipment.

I trust that this will make it clear that no criticism of Plessey products was intended, nor was it deserved.

Received 20th March 1957.

Over and Out

THIS MONTH sees the end of my term as Chairman of the Graduates' and Students' Committee. Perhaps I may be allowed therefore a slight personal digression.

One of my main concerns during these three years has been to increase the interest shown in the Section's activities by its members. These activities come in four varieties, three visible and one invisible.

The more tangible ones are lectures, visits and social activities. The latter two functions are usually very well supported and generally are over-subscribed. Lecture attendances have, however, suffered a marked drop in the past year, an affliction which has also hit other groups of this and other Societies. I feel that this discrepancy of interests is, to a certain extent, inevitable. Nowadays the dissemination of all kinds of aeronautical information (except the most useful or most incriminating which is, of course, "secret") is so widespread that the average student and graduate can more than satisfy his lust for knowledge without the toil of attending lectures. The exception is, I hope, the type of lectures which will be given to the Section by Messrs. Masefield and Stephens where leaders of the field express their concepts of present and future developments. On the other hand, the greatly increased ratio of technicians to hardware means that the opportunity of seeing different sorts of aircraft and establishments is as limited, if not more so, as it ever was. The popularity of our dances seems to have improved markedly since we had a bar.

Our mystical activity consists of reporting the views and ideas of Graduates and Students to the Society. I have referred to this before and also in the Section's Annual General Report. Briefly, to report your views we need to know them accurately and correspondence, either privately or via this page, is an excellent way of doing so.

In what ways, therefore, can we increase the interest of members in the Section and thereby the influence of the Section in the Society as a whole? I think that in the "front" varieties they are as follows:—

1. The Committee can arrange more interesting lectures which should be attended by more interested Graduates and Students.
2. Graduate and Student Members should offer lectures to the Committee to be read before the Section.
3. Graduates and Students should submit more work for consideration for such awards as the Usborne and Pilcher prizes.

These three items are by way of dressing the Section's window and in themselves contribute only partly to any future success. We must all make a marked effort to stock the Section with new members. An encouraging start has been made in this and last year about 60 per cent of all new elections to the Society were either Graduates or Students. These two grades now contain 25·3 per cent of the Society's total membership. As the Section's strength is constantly whittled away by elections to higher grades the rate of recruitment to increase its size must, perforce, be high. I think these two percentages are significant because they show the relative influence which Graduates and Students can exert in favour of their particular interests.

I am not suggesting, I hope, that you should dedicate your lives to the Society. What I do think though is that you should ally your professional career with your membership and activities in the Society. The form of this alliance, which could perhaps be on the same lines as the British Medical Association, is something which the Committee have spent some time in discussing in the past year and it certainly cannot be resolved or recommended at the drop of a hat. The Committee would be most interested to hear the views of Section members on this point and to know whether they favour this idea of an "aeronautical B.M.A."

On a different vein the Section's A.G.M. has come and gone. We had hoped to have a member from each firm and college on the new Committee but unfortunately the attendance was somewhat stratified. We are missing representatives from Hawkers, Faireys, Imperial College, Bristols (London) and Northampton and hope that members from these firms will volunteer to act as contact men for us among their fellows.

Finally, it is with a great deal of regret that I have come to the end of my term as Chairman of the Section. I have found the work extremely interesting and, I hope, constructive. In it all I have been very ably backed by the previous and present Committees. I would like to mention Mr. E. J. Catchpole who served on the Committee for a number of years and contributed greatly to its successes, Mr. J. Cownie, our lectures secretary, who deputised for me during my stay in the U.S.A., Mr. N. Benson, our visits secretary, Mr. Coe, our treasurer, and Mr. Stewart, our secretary. They have all worked extremely hard and deserve your thanks.—P. A. HEARNE.

Summer Party

WE shall be holding our summer party this year on Friday 21st June at 4 Hamilton Place from 8.00-11.30 p.m. As was the case last year, every effort will be made to give a full evening's entertainment at the lowest cost; free wine, beer and other drinks will be provided.

The summer party last year was the first of its kind and proved very popular; the sale of tickets had to be limited. This year we are trying to make it even better—for example, we are hoping to have a skiffle group. We shall be pleased to receive suggestions about the form the party should take.

Full details will be given next month.—J.R.C.

Notice of Lectures

ON Wednesday 17th April, Mr. P. G. Masefield, M.A., F.R.Ae.S., will talk on "Problems and Prospects in Air Transport." As Managing Director of Bristol Aircraft and former Chief Executive of B.E.A., Mr. Masefield's lecture should be of immense interest to everyone in the Section and we hope there will be a large attendance.

On Wednesday 15th May, Mr. W. H. Stephens, M.Sc., A.F.R.Ae.S., Head of the Guided Weapons Department at R.A.E., will lecture on "Guided Weapon Research and Development." Members will need no encouragement to attend one of the far too few expositions of this art.

Lotus Visit—Errata

There were certain inaccuracies in last month's account of the visit to Lotus Engineering.

Mr. Michael Costin's correct title is Experimental Manager, and his duties as such were described in the account.

The four sports cars for the Sebring race in Florida on 24th March were not all 1500 cc. cars, some being powered by the 1100 cc. version of the Coventry-Climax ex-fire pump engine. It should have been made clear that the Formula 2 racing car has a new type of Coventry-Climax racing engine, which is developed from the sports engine, but having in fact nothing in common with the fire pump engine. The rivets used in the chassis are "Pop" rivets, Chobert rivets being a proprietary make which are not used.—N.K.B.

Visit to the Southern Air Traffic Control Centre

The centre at Harmondsworth, which was visited by two parties on the 16th of February and March, is responsible for all of England and Wales south of the latitude of Birmingham.

The Centre Superintendent explained how their business is the achievement of the required separation standards for civil aircraft on the airways, which are official air corridors wherein these special safety standards are maintained. The airways are defined by radio ranges and fan markers, to which the civil aircraft tunes in. Whilst any aircraft is on a certain sector of an airway, it is in contact with one controller on his particular radio channel, and he is informed of its progress along the airway. This progress is monitored by radar at the centre, both in azimuth and altitude.

The radar equipment, which has been installed with a view to maximum serviceability by duplication and provision of standby units is theoretically capable of being restored to normal service in the event of any failure within 3 minutes, including tracing the fault.

The radar consists of a rotating scanner system of some 50 miles range, but which is affected by permanent echoes at close range, *e.g.* the North Downs, various pylons, and so on. For shorter ranges, up to 20 miles, there is the clever M.T.I. (Moving Target Indicator) system, which uses the Doppler principle to cancel out signals from stationary objects, so that permanent echoes are eliminated. On the first visit, some members saw on the radar scopes of this system, the progress of the Queen's Viscount just after taking off for Lisbon. There is also a nodding scanner system, which operates up to 50 miles, indicating altitude, but only in one direction at a time. These radar systems are more particularly concerned with the approaches to London Airport, where smaller separations have to be accepted, but closer watch is possible.

The control room has yellow-deficient lighting for the controllers to work by, and yellow filters on the radar scopes. This is necessary because the scopes would not leave a trace long enough in daylight to indicate the direction of motion of the aircraft.

There was a room full of recording equipment, where the controllers' conversations with pilots are recorded on film, and a teleprinter room where operators listen on the various radio channels, and pick out information to be sent to London Airport, giving the Air Lines up-to-the-minute data on the progress of their aircraft in the area.

The visit gave an insight into the work of some of these people; exacting, mentally exhausting, extremely monotonous work of great responsibility, for which they earn every penny of their pay, which is high by aircraft industry standards.—N.K.B.

THE LIBRARY

Reviews

ADVANCES IN APPLIED MECHANICS. *Vol. IV. Edited by H. L. Dryden and T. von Kármán. Academic Books, London, 1956. 413 pp. Illustrated.* $10.

This is the fourth volume in a series initiated by Richard von Mises, who died in 1954. The present Editors are H. L. Dryden and Th. von Kármán, while the Managing Editor is G. Kuerti and the Associate Editors are F. H. van den Dungen, L. Howarth and J. Pérès. The editorial team is thus strong and international.

Nine authors, of whom eight appear to be American and one Swiss, contribute articles on a greatly diversified set of topics. No review of a book such as this would be adequate without a list of the titles and authors of the contributions. These are: The Turbulent Boundary Layer, F. H. Clauser; Non-Linear Elasticity, T. C. Doyle and J. L. Ericksen; Physical and Statistical Aspects of Fatigue, A. M. Freudenthal and E. J. Gumbel; Three-Dimensional Boundary Layer Theory, F. K. Moore; Dislocation Theory of Plasticity of Metals, G. Schoeck; The Poincaré-Lighthill-Kuo Method, H. S. Tsien; On the Concept of Elastic Stability, H. Ziegler. It will be seen that the range of topics is very wide but every one is certainly important and the subject of contemporary research. A review authoritative in all the fields of investigation covered could not be provided by anyone, except possibly the Editors themselves and one or two others: the present reviewer certainly makes no claim to comprehensive competence and must content himself with giving his general impressions of the book. In general, then, this is a collection of interesting and stimulating essays by contributors who are themselves in the thick of the action. The book should certainly be consulted by investigators concerned with the particular topics discussed but it will not make easy reading for the non-expert.—W. J. DUNCAN.

HIGH SPEED FLIGHT. *E. Ower and J. L. Nayler. Hutchinson's Scientific and Technical Publications, London, 1956. 227 pp. 30s.*

There is probably no more difficult task than to write, for the ordinary reader, a popular exposition of a subject that is fundamentally of great mathematical and technical complexity. Such a subject is that of high-speed flight, which is, however, also one of compelling interest on account of the almost unbelievable things that have been accomplished in recent times in the field of aeronautics. The volume under review, by two scientists who have had close contact with the development of aeronautical science from its earliest days, is a very interesting and successful attempt to present the subject of high-speed flight in terms that can be understood by any educated reader with a little knowledge of basic scientific facts. Even though such a reader can hardly be expected to appreciate all that is written " between the lines " he will nevertheless obtain a clear picture of the many and difficult problems that have confronted those who have developed high-speed aeroplanes.

After a brief introduction detailing the main problems involved the authors help the less well-informed reader with chapters on the fundamentals of flight and on the speed of sound. They then describe the engines for high-speed aircraft and the structural and material considerations involved. There are chapters on the future problems of very high speeds, including a full treatment of the human factor; on research and experiment in aeronautics, and on aids to flight. In the last chapter some account is given of guided missiles, although of course this subject cannot be very fully treated at the present time, as so little has yet been published.

It is hardly to be expected that such an ambitious attempt as this volume should be free from all criticism. There are a few obvious slips, such as the transposition of the captions in the curves of Figures 11, 7 and the statement on page 40 that L/D is usually a *minimum* at a small value of the lift instead of a *maximum*. Actual errors are few; there is one on page 46 in the discussion of the effect of density on absolute coefficients and on page 163 in the description of the action of electric balances, but these are mere technical details and do not affect the general argument at all. On page 118 it is stated that present day aeroplanes may take 27 times as long to design and build as those of 1945. Surely this should have been 27 times as many man-hours, a rather different matter.

The book, including its numerous illustrations, is exceedingly well printed and is very easy to read. It should fill an important place in aeronautical literature by making some idea of the problems of high-speed flight intelligible to those who have only a limited background of scientific and engineering knowledge.—ERNEST F. RELF.

MOLECULAR FLOW OF GASES. *G. N. Patterson. Chapman and Hall, London, 1956. 217 pp. 60s.*

This monograph is devoted to the application of the kinetic theory of gases to the study of problems of aerodynamic interest, such as those associated with shock waves and with the boundary layer. It is based on lectures to advanced students in engineering, physics and applied mathematics.

The first part contains a fairly detailed derivation of the main relations in gas kinetic theory, including the H theorem and the transport equations. The propagation of disturbances in a medium is discussed in two stages; the isentropic process is treated first, the non-isentropic process which follows is given in much more detail. A good deal of experimental as well as theoretical material is provided on the properties of shock waves. The effect of internal degrees of freedom, of collision times and hence relaxation phenomena, is considered fairly fully. Experimental methods of measuring the relaxation time are discussed and the experimental consequences of its existence on the drag on a wing are pointed out.

The boundary layer equations are deduced subject to the assumption that the non-Maxwellian behaviour of molecules is confined to a small region in the immediate neighbourhood of the boundary. The momentum transfer and the heat transfer to a boundary are then calculated and the results of calculations are compared with experiment. In the final section of the book, the theory of momentum and heat transfer is extended to the case of rarified gases.

The monograph is well documented; references to the original literature are given at the end of each chapter, and the main mathematical techniques used are summarised in appendices. It is well written and well produced and can be warmly recommended.—M. BLACKMAN.

FATIGUE IN AIRCRAFT STRUCTURES. *A. M. Freudenthal. Academic Press Incorporated, New York, 1956. 456 pp. Illustrated. $12.00.*

The literature relating to fatigue dates from over a hundred years ago. From then on, until nearly the close of the last century, additions to it were made at a slowly increasing pace. The problem, although intriguing to the few physical metallurgists of the time, was by no means a nightmare to the contemporary engineer. Wöhler and others, without understanding its mechanism, had clearly and convincingly demonstrated that the endurance of components, subjected to repeated stresses could be almost indefinitely increased by a mere reduction in the magnitude of this stress. That is to say, whatever the cause of the phenomenon, it was defeatable. The price was a mere increase in weight which, then, could be faced with comparative equanimity. With the invention of the motor-car, to be followed a generation later by that of the aeroplane, the picture, however, markedly changed. The price, initially regarded as reasonable, was increasingly harder to pay, for success in the new fields came to depend, more and more on the saving of weight. The metallurgist, as a consequence, was called upon to produce and has succeeded in producing materials of higher and higher specific strength. Their resistance to fatigue has not invariably correspondingly increased—a statement which might be regarded by some, such as airframe designers, as something of an understatement.

So much for the past: now for something of the present: today, due to the repercussions engendered by the vigorous demand for light structures and mechanisms which will not, within a prescribed period, fail by fatigue, a vast literature relating to it has come into being. There are four decent books on the subject and some not so decent but, to prevent keen disappointment, it should at once be emphasised that not one of these is by any means indecent. Papers devoted to fatigue are now numbered in thousands and they are increasing at an utterly embarrassing rate. To mention but a few sources: at the Colloquium at Stockholm in 1955, thirty-five were presented; at the International Conference in New York less than a year later (the report of which forms the excuse for this review), there were a further twenty-two; at yet another International Conference held in London at the end of last year, there were another eighty papers. In February of this year, eight more were presented to the Royal Society—surely reproduction in this field, at this rate, should now be subjected to strict Malthusian discipline?

"Fatigue in Aircraft Structures" is a 456 page record of a three-day Conference at Columbia University. As has already been said, twenty-two papers were presented and now the aeronautical engineer, suffering these last ten years from a surfeit of such efforts, nearly as gravely as did Henry I from one of lampreys, is asked to pay 57/6 for it. In spite of all importunities, he should hesitate and, while hesitating, should recall what kind of man is soon parted from his money.

From the title of the work—"Fatigue in Aircraft Structures"—he might well expect its contents to be concerned with fatigue in aircraft structures. He would, however, in some measure be betrayed by his own simplicity. Half a dozen of the contributions do not do this. Further, one of them relates to an interesting aspect of fatigue which, however, occurs at stress levels not experienced in aircraft. Very few of the contributions contain anything new, while many, without in any degree revealing the spiritual convictions of the authors, indicate that they firmly believe in resurrection as applied to papers and in fact, in one case, in repeated resurrection. In damning this work with non-luminous praise, two papers deserve to be excluded, one by Phillips, on cracks, and the other by Giddings, on the fatigue problem in aircraft design. Both these deserve warm commendation.

When in old age, an at present young engineer looks back on the plethora of conferences, symposia and meetings on fatigue, which during the last decade he has attended, he will surely be able to say, like Omar of old:—

> "Myself when young did eagerly frequent
> Doctor and Saint, and heard great argument
> About it and about: but evermore
> Came out by the same door wherein I went."

P. L. TEED.

GUIDED MISSILES IN WAR AND PEACE. *Nels A. Parson, Jr. Harvard University Press, Cambridge, Mass. (O.U.P.), 1956.*

This book, published quite recently by the Harvard University Press, is obviously written by an enthusiast in the hope of attracting the interest of potential users in the military Services and inspiring them with equal enthusiasm for guided missiles in all forms. The avowed objective is to study the impact of guided missiles on military operations and to describe their technical characteristics, so as to familiarise military and civil leaders with these new weapons, how they work and how they may be used. It is at first a surprise to learn that the subject matter is the outgrowth of a thesis for a Masters Degree at the University of Southern California, but the general standard and tone subsequently proves rather typical of the efforts of a graduate student striving to master and summarise a large and rambling subject with some semblance of coherence. The task is made many times more difficult by security restrictions, applied, one suspects, more vigorously to a serving member of the U.S. Army than to the legion of American aeronautical journalists who appear so free to publish the latest developments in the missile field.

The first three chapters deal briefly with the history of German missile development before passing on to a very elementary exposition of missile aerodynamics, guidance and propulsion. The standard here is suitable for the non-technical reader and the main characteristics of missile flight are simply explained, with clear diagrammatic illustration. Chapters 7-10 discuss the use of guided missiles in air, naval and land warfare; inevitably the answer to nearly every military problem of the future is said to be the guided missile, although the role of the human operator in recognising a changing battle situation and his ability to exercise judgment are still noted. With the transition to guided missiles, the need for specially trained manpower to operate and maintain the complex equipment is emphasised. There is an interesting accent on the potential value of guided missile submarines, especially with nuclear propulsion; the possible strategic role of submarine-launched atomic bombardment missiles is noted, without adding much to the argument between the protagonists for the air and seaborne strategic threats. The influence of the current struggle in U.S.A. for control of the intercontinental ballistic missile is hinted by arguments that Army Commanders must be able to attack enemy concentrations of airborne troops or missile bases a thousand miles distant. The future importance of reconnaissance missiles is also remarked. The final chapter on "missiles of peace" muses on the use of rockets for upper atmosphere research and the problems of escape from the earth's gravitational field. A salutary note of caution is sounded on the navigational problems of would-be space travellers.

Apart from some irritating attempts to popularise the subject, for example, by such chapter headings as " From Wan Hu to Von Braun " or " Flying Cuspidors and Stovepipes," and the rather sweeping assertions made on the military use and value of the various types of missiles, the book gives an introduction which should be quite useful for those who are relatively ignorant of guided missiles. The illustrations include a number of striking photographs of American missiles of all types.—W. H. STEPHENS.

ROCKET. *Air Chief Marshal Sir Philip Joubert de la Ferté. Hutchinson, London, 1956. 190 pp. Illustrated. 18s.*

All those in any way familiar with Sir Philip's career, or with most of his previous public statements and writings, will expect this to be a very readable, interesting, stimulating and provocative book—and they will not be disappointed.

What they will not expect, in a book entitled " Rocket," is a great deal about photographic reconnaissance, international politics, and Service organisation. However, they will get that, too; there is even a plea for " drastic birth control . . . particularly amongst the Oriental and Catholic races." Even the author, in his introduction, mentions the " apparent irrelevance " of his later chapters.

However, they are not *quite* so irrelevant as all that; the thread which connects all these unlikely subjects is discernible, once one has appreciated the story Sir Philip has obviously wanted to tell, and his somewhat unconventional method of telling it at least has the merit of holding the reader's attention, and making him wonder whatever is coming next, as if he were reading a good detective story. He will find an account of the history of rocketry, and especially of the German effort culminating in Peenemunde; of the British P.R.U. and Intelligence work in connection with the V-weapons, and the R.A.F. raids on their research establishments, factories, and launching sites; of the actual V.1 and V.2 operations, and the Allied counter-measures which these provoked.

All this is by way of preamble to the book's main theme, an only slightly over-simplified expression of which might be to say that, in the world as it is today, the ballistic rocket with nuclear warhead is the dominant weapon, and almost everything else is a waste of time. Sir Philip apparently agrees with Lord Hives, who was quoted in the recent report of a Commons' Select Committee on Estimates (" The Supply of Military Aircraft ") as saying: " It would put all the aircraft makers out of business. . . ." (Except that the aircraft makers would presumably be called upon to make it!)

Of course, this particular question, as our American friends would say, is probably the 64,000-dollar one in all the current reconstruction of the British Defence programme; we are now the only country, apart from the U.S.A. and the U.S.S.R., which maintains a strategic bomber force, and if we intend to remain in this class, we shall presumably need to have the ballistic rocket as the next step. If we do, then we shall have to go without something else—but if we do not, then by 1965 or thereabouts it will be increasingly difficult for the British Prime Minister to claim that we are still, in the military sense, a first-class power.

It is, to say the least, very interesting to consider that the new Defence Minister, on whose shoulders rests the greatest individual responsibility for deciding this matter, is Duncan Sandys, who, as a war-time Army major, commanded the first rocket Z-battery, and later chaired the Government's special committee dealing with counter-measures against the German V-weapons. Of his activities in those days, one can read in the book under review; of his present job, one can only say that he is not to be envied in the tasks he has to undertake, and the hard decisions he must reach—even with all the expert advice that will no doubt be available to him. One can well imagine how conflicting this is likely to be, and he will probably feel that he has been visited by the famous Chinese curse: " May you live in interesting times. . . ." We certainly do.

All this, of course, makes Sir Philip's present book highly topical. It is to be recommended, although for this reader at least it was slightly marred by its tendency to range over quite such a wide variety of subjects, in such a comparatively small volume; by a certain racy disregard for accuracy of detail; and by its over-statement of a good case. Inter-continental ballistic missiles are not available yet, even to the Americans or the Russians, and even when they are, it is unlikely that they will completely supersede piloted aircraft for all the present duties of Bomber Command. However, perhaps Sir Philip believes that one has to over-state one's case, to be sure of making one's point: within reason, this is unfortunately often true, when the opposition is very vocal.—A. V. CLEAVER.

RADIO AIDS TO AIR NAVIGATION. *J. H. H. Groves. Heywood, London, 1956. 138 pp. Illustrated. 21s.*

Somewhere in the recollections of all who aspire to seek their livelihood or pleasure in the air, must be the tattered note book, full of hurried jottings and nearly illegible diagrams penned during one of the many courses attended. If Mr. Groves's note books were as comprehensive and well laid out as his publication now under review, he was indeed a fortunate student. His book forms a compendium of facts, figures and explanations concerning most of the radio equipments in use today in civil aviation. Beginning as it does with a brief revision of the behaviour of electrical energy and radio waves, this book soon introduces the reader to the various systems in general, and to the equipments in particular.

There is a comprehensive chapter on the various hyperbolic chains and their *modus operandi*, with notes on the scope and coverage thereof from the cockpit's point of view. This book's real forté, however, lies in the chapters devoted to radar, both airborne and ground equipment. So many publications on the market today concerning radar tend to fall into one of two well defined camps. There is the " Stone in the pond " brigade who, while providing excellent reading for the *ab initio* student or the mildly interested general public, fail to offer any assistance to the holder of an A.L.T.P. licence thirsting for information. Then there are the books produced by electronic scientists, for electronic scientists, that any other reader would cast aside with horror and amazement. Mr. Groves has, however, steered a straight course mid-way between these two encampments. He is thus able to provide the reader with all the basic information required, not only to use the equipment, but to know how " the darn thing works." This is especially true in the most welcome chapters on aids to Air Traffic Control and Precision Approach Radar. Food for further thought is provided by short notes on the future aids and trends in the overall field of both long and short range navigation.

Mr. Peter Masefield has, in his foreword, summarised by saying, " As an ' aid ' to examination work and as an ' aid ' to keeping abreast with air radio today, I recommend this book to all concerned."—B. E. J. HEARD.

TRANSISTORS HANDBOOK. *W. D. Bevitt. Prentice-Hall Inc., New Jersey. 1956. 410 pp. Diagrams. $9.*

This book deals mainly with the characteristics and applications of transistors and is directed towards potential users.

The first eleven chapters are concerned with a general description of the operation of the transistor and its characteristics. The introduction gives a good overall picture of the transistor up to the present day and mentions a number of ways in which some of the shortcomings of the earlier transistors are being overcome. The author has kept the description of the physical basis of the transistor action intentionally brief, but because of this some of it may be difficult to the newcomer. It is nevertheless quite useful for reference purposes. There are interesting notes on the ways in which the desirable and undesirable features of the characteristics of the transistors may be controlled during manufacture. Chapters 3, 4 and 5, which deal respectively with point-contact transistors, junction transistors and power transistors, describe their characteristics and give the equivalent circuits. Typical values for the various working conditions are given, together with the limiting conditions for typical transistors of the various kinds in different applications, including, for example, considerations relating to maximum output power in audio frequency output stages. Chapters 6 to 11 deal with measurements of transistor characteristics and parameters, analysis of the basic transistor amplifier circuits, tetrode and pentode transistors, photodiodes and phototransistors, practical considerations in transistor circuits and noise and temperature effects. The treatment is simple and the explanations are clear. The description of the behaviour of transistors operating with large signals is very brief and is limited to point-contact transistors; there appears to be no mention of "hole-storage" effects which are particularly important in large signal circuits.

The second half of the book—chapters 12 to 21—deals with the applications of transistors. These include audio frequency, power, and radio frequency amplifiers; a.f. and r.f. oscillators; amplitude modification and detection; frequency modulation and demodulation; radio and television receivers; relaxation oscillators; computer and miscellaneous applications of transistors. The author has drawn heavily on published works, with due acknowledgment—there are over 150 references, with the result that the standard varies considerably. A particularly bad feature is the large number of different transistor symbols used. At least five different symbols are used for the point-contact transistor and three for the junction transistor, and no distinction is made between these two types which have totally different characteristics. These last ten chapters contain much useful information, but it is unfortunate that the author did not give more emphasis to the general considerations relating to each particular application before the description of the actual circuits rather than embodying the special points in the actual circuit descriptions themselves. This book should prove useful to circuit designers who require information about the various published circuits in a compact form.—R. L. GRIMSDALE.

AIRCRAFT CAMOUFLAGE AND MARKINGS 1907-1954. *Bruce Robertson. Harleyford Publications Ltd., Marlow, Bucks, 1956. 212 pp. Illustrated. 45s.*

In his preface, the author is careful to indicate that this book is intended both to assist aircraft modellers in achieving accuracy of detail in their products and to impart an understanding of aircraft markings to those who are interested in aircraft. In these objects he succeeds admirably, but he has also provided a great deal of factual information which will appeal strongly to most people who are interested in aircraft, and not least to the aircraft historian.

The numerous photographic illustrations so essential in a work of this kind have been carefully selected to illustrate the author's notes, and are liberally supplemented by sketches and several colour plates. They give an admirably representative coverage of the principal British Service aircraft used before, during, between and after the two World Wars, as well as many machines of enemy and other nationalities. A welcome appendix deals with the lighter-than-air craft of the 1914-18 war.

There can be no doubt that this book covers its subject more thoroughly than any other has ever done; moreover—and more importantly—it has the admirable quality of accuracy. It is not quite faultless: there are, for instance, a few omissions, but they are not likely to trouble any but the most captious—and knowledgeable—of the book's readers. What one might reasonably have expected in a book of this quality is better proof-reading. A fair number of spelling errors occur: in particular, one fears for the flying sorcerer's apprentice who attempts the British Cauldron method of marking his scale model D.H.5.

In short, this book is a thoroughly worthwhile addition to any aeronautical library: it should do much to augment the little learning which (as the book's editor seeks to remind us) is indeed a dangerous thing.—J. M. BRUCE.

FIFTY YEARS OF BROOKLANDS. *Edited by Charles Gardner. Heinemann, London, 1956. 160 pp. Illustrated. 25s.*

This book is divided approximately into two halves, the first dealing with motors and motor racing, the second dealing with the aeroplane story. Only the latter is considered here.

The history of Brooklands aerodrome can also be divided into two halves, the first, starting with the arrival of A. V. Roe, as he then was, ended with the commencement of the 1914 war. This was the period when Brooklands was one of the foundation stones of British aviation. In the second half, from 1914 to date, Brooklands became a Service and commercial aerodrome where aeroplanes are built and tested. This latter part of Brookland's history is adequately dealt with in this book with a wealth of photographs and a text which gives a very complete idea of the work carried on there, and of the numerous types of aeroplanes which flew there for the first time.

But the pre-1914 period requires different treatment. Brooklands was then the work place of a number of young enthusiasts who spent all their time and any money they had in the attempt to produce aeroplanes which would fly, and in spite of there being, in the early days at least, no suitable engines available they often succeeded. This is the part of Brookland's history which most deserves to be written, and the part which the author, with his condensed style, has been least successful in describing.

Generally the book is well produced. There are a number of illustrations, most of them excellent and the number of errors is not greater than one usually finds in books of this type, and many of these are unimportant. The extreme compression the author has had to use in his text reduces the pleasure one expects in reading such books, but it seems to have been inevitable. It will be a useful addition to aviation history, mainly as a book of reference.—W. O. MANNING.

ENGINEERING MECHANICS. *Fourth Edition. S. Timoshenko and D. H. Young. McGraw-Hill, New York, 1956. 529 pp. Diagrams. 56s. 6d.*

This is the Fourth Edition of a book too well known to need reviewing here in full. The previous edition appeared in 1951 and the first, in two volumes, in 1937. A large part of the statics section has been rewritten with the idea of making the subject easier to teach and the large selection of problems and worked examples has been further increased to include more elementary problems and examples using numerical data, so as to avoid over-emphasising algebraic manipulation. The book can also be bought in two volumes, Statics and Dynamics, with an increase of 13 per cent in total price for this form.

WINGS OVER THE ATLANTIC. *Robert J. Hoare. Phoenix House, London, 1956. 160 pp. Illustrated. 15s.*

This book has the two virtues of being interesting and useful. As the title implies, it records the early attempts, successful and not-so-successful to cross the Atlantic both direct and " with stops." Every effort should be made to sell the book in America where Alcock and Brown's " first " is still forgotten in favour of Lindbergh. It is well illustrated and indexed but surely Lord Inchcape's daughter's name was Mackay and not Mackey?—F.H.S.

1956 HEAT TRANSFER AND FLUID MECHANICS INSTITUTE. *Stanford University Press, Stanford, California; O.U.P., London, 1956. 278 pp. Diagrams. $5.75. 45s.*

This volume is a photo-reproduction of the manuscripts of the papers read at Stanford University, California, in June 1956. The meeting was the ninth of a series initiated in 1948 for the purpose of making available to engineers of the Western region a programme of fundamental research in heat transfer and fluid mechanics. No discussions are included with the preprints, and the papers will appear later in the publications of the sponsoring professional societies, which include the Institute of the Aeronautical Sciences, the American Society of Mechanical Engineers and the Society of Automotive Engineers.

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Reports

AERODYNAMICS

Boundary Layer

A theoretical and experimental study of the boundary layer flow on a 45° sweptback wing. F. M. Burrows. CoA Report 109. (October 1956).

The experiments were performed, in flight, on a large untapered, untwisted, 45° swept-back half wing mounted as a dorsal fin upon the mid upper fuselage of an Avro Lancaster (P.A.474), the Reynolds number range thus achieved being $0{\cdot}88 \times 10^6$ — $1{\cdot}92 \times 10^6$ per foot. Curves are presented giving details of the measured distributions of static pressure, chordwise loadings, and the boundary layer flow, the latter in extensive detail, for wing geometric incidence in the range 0° — 10°, upper and lower surfaces, and for test Reynolds numbers in the range defined.—(1.1.2.1).

The direction of flow in the laminar boundary layer on an infinite yawed cylinder. K. D. P. Sinha. C.P. 295. (1956).

In a previous report the exact solutions of the spanwise laminar boundary layer on an infinite yawed cylinder with distributed suction, were given for all the known exact solutions of the chordwise boundary layer for the chordwise velocity distribution, $U=U_0x^m$. Here the same class of exact solutions has been used to investigate the direction of the velocity vector, and hence the curvature of the streamlines and the secondary flow.—(1.1.1.1).

On possible similarity solutions for three-dimensional incompressible laminar boundary layers. II—Similarity with respect to stationary polar coordinates. H. Z. Herzig and A. G. Hansen. N.A.C.A. T.N. 3832. (November 1956).

Solutions of mainstream flow patterns for three-dimensional, laminar, incompressible thin boundary layer flows (over flat or slightly curved surfaces) having similarity with respect to stationary polar co-ordinates in the plane of the surface are derived. The solutions are summarised in a table.—(1.1.1.1).

Compressible Flow

An experimental investigation of Meksyn's transonic inviscid flow theory. C. S. Sinnott. C. P. 302. (1956).

The solution of the two-dimensional transonic flow equations obtained by Meksyn is critically examined for the flow past a bicusped aerofoil at zero lift. Comparisons with experimental results are made.—(1.2.2.1).

A theory for stability and buzz pulsation amplitude in ram jets and an experimental investigation including scale effects. R. L. Trimpi. N.A.C.A. Report 1265. (1956).

From a theory developed on a quasi-one-dimensional flow basis, it is found that the stability of the ram-jet is dependent upon the instantaneous values of mass flow and total pressure recovery of the supersonic diffuser and immediate neighbouring subsonic diffuser. Conditions for stable and unstable flow are presented. A simple theory for predicting the approximate amplitude of small pressure pulsation in terms of mass flow decrement from minimum-stable mass flow is developed and found to agree with experiments.—(1.2.3.1 × 27.4).

Spreading characteristics of a jet expanding from choked nozzles at Mach 1·91. M. D. Rousso and L. E. Baughman. N.A.C.A. T.N. 3836. (December 1956).

Total-temperature surveys were made to determine the gross spreading of jets expanding from axisymmetric convergent and convergent-divergent nozzles. The nozzles were located in the base of conically boat-tailed bodies of revolution Surveys were made between the nozzle exit and a station 8 nozzle diameters downstream of the jet exit for jet pressure ratios from 2·5 to 0·16.—(1.2.3).

Fluid Dynamics

On the stability of a laminar wake. C. H. McKoen. C.P. 303. (1956).

A perturbation method of solving the problem of stability in an unlimited field of flow is developed and used to investigate the stability of the laminar wake formed by a flat plate.—(1.4).

Internal Flow

Secondary flow in compressor blades at high negative incidences. W. D. Armstrong. C.P. 297. (1956).—(1.5.4.2).

Turbulent diffuser flow. B. S. Stratford. C.P. 307. (1956).

Exact solution of the equations of motion are possible for various types of diffuser. Application is restricted to that part of each diffuser in which the velocity profile has attained a constant shape. The solutions are expressed in terms of the distribution of the mixing length, which effectively is the length of the mean free path of the turbulence.—(1.5.1).

Loads—*see* Wings and Aerofoils
Testing and Instruments
See also Aeroelasticity

Performance Estimation

Charts for estimating performance of high-performance helicopters. A. Gessow and R. J. Tapscott. N.A.C.A. Report 1266. (1956).

Theoretically derived charts are presented for use in predicting profile-drag—thrust ratios of rotors having hinged blades with 0°, −8°, or −16° twist. Limit lines showing the conditions of onset of stall are presented, and the effects of blade twist on the stall limits are discussed.—(1.7).

Stability and Control

Experimental investigation at low speed of the effects of wing position on the static stability of models having fuselages of various cross sections and unswept and 45° sweptback surfaces. W. Letko. N.A.C.A. T.N. 3857. (November 1956).

An experimental investigation was made to determine the effects of wing position on the low-speed static longitudinal and static lateral stability derivatives of aeroplane models having fuselages of square and rectangular cross sections and unswept and 45° swept-back surfaces.—(1.8 × 1.10.2.2).

Thermo-aerodynamics

Investigation of heat transfer from a stationary and rotating ellipsoidal forebody of fineness ratio 3. J. P. Lewis and R. S. Ruggeri. N.A.C.A. T.N. 3837. (November 1956).

Experimental convective heat transfer was obtained for a 20-inch-diameter forebody for air speeds up to 240 knots, rotational speeds up to 1,200 r.p.m., angles of attack of 0°, 3°, and 6° and both uniform surface temperature and uniform input heat density. The results agree well with theoretical predictions.—(1.9.1 × 34).

Wings and Aerofoils—
See also Stability and Control

Tests at high subsonic speeds on a 10 per cent thick pressure-plotting aerofoil of R.A.E. 104 section. E. W. E. Rogers et al. R. & M. No. 2863. (1956).

A series of tests has been made at the National Physical Laboratory 20 in. × 8 in. High Speed Wind Tunnel on a two-dimensional pressure-plotting aerofoil of five inches chord and R.A.E. 104 section. Force coefficients, surface pressures, and flow patterns were determined for the aerofoil through a range of Mach number at incidences up to 8 degrees.—(1.10.2.1).

The reflection effect of fences at low speeds. J. Weber et al. R. & M. No. 2977. (1956).

The effect on the flow over a swept wing is considered of vertical plates of small height—commonly called "fences." It is shown, as might be expected that, the nature of this effect is that of a partial-reflection plate. The effect of this partial reflection on the pressure distribution over the wing on either side of the fence has been investigated theoretically and by means of pressure measurements at low speeds on an untapered 45° swept-back wing. The proportion of full-reflection effect has been determined experimentally for various shapes of fence. Methods are described for calculating the changes in pressure distribution, chordwise loading and spanwise loading.—(1.10.1.2).

Note on the effect of size and position of end plates on the lift of a rectangular wing in a wind tunnel. A. S. Halliday and D. K. Cox. C.P. 305. (1956).

Experiments have been made in a wind tunnel to determine the minimum size of end plate which would be effective in producing approximately two-dimensional flow conditions past an aerofoil at low incidence. The variation of effective aspect ratio with size of plate is considered. Theoretical and rough experimental aspect ratio factors are confirmatory. —(1.10.2.2).

Charts of the theoretical wave drag of wings at zero-lift. R. A. Bishop and E. G. Cane. C.P. 313. (1957).

Charts are presented for the theoretical wave drag at zero-lift of straight-tapered wings with streamwise tips, and with double-wedge or parabolic-arc sections. A bibliography of theoretical reports is included, and reviewed.—(1.10.1.2).

Pressure measurements and flow investigation on delta wings at supersonic speed. G. Drougge and P. O. Larson. F.F.A. 57. (1956).

Pressure distribution measurements were carried out on two delta wings, one with a sharp and the other with a rounded leading edge. The sweep angle was 70° and the investigation was made at about a Mach number of 1·5 at different angles of attack. From the measurements the lift distributions were evaluated and were compared with the linearised conical-flow theory.—(1.10.2.2).

On the kernel function of the integral equation relating lift and downwash distributions of oscillating wings in supersonic flow. C. E. Watkins and J. H. Berman. N.A.C.A. Report 1257. (1956).

A suitable form of doublet potential that serves as a basis for deriving the kernel function for supersonic flow, corresponding to the kernel function for subsonic flow presented in N.A.C.A. Report 1234, is derived by using a cut-off or unit function.—(1.10.1.2 × 1.6.3).

A study of the zero-lift drag-rise characteristics of wing-body combinations near the speed of sound. R. T. Whitcomb. N.A.C.A. Report 1273. (1956).

Results are presented which indicate that near the speed of sound the zero-lift drag-rise of a low-aspect-ratio thin wing-body combination is primarily dependent on the axial development of the cross-sectional areas normal to the air stream. Results are also presented of an investigation wherein applications of this concept to the reduction of the drag-rise increments of representative wing-body combinations are made.—(1.10.2.2).

Lift and pitching-moment interference between a pointed cylindrical body and triangular wings of various aspect ratios at Mach numbers of 1·50 *and* 2·02. *J. N. Nielsen et al. N.A.C.A. T.N.* 3795. (*December* 1956).

The lift and pitching moment characteristics of a body alone, six triangular wings of various aspect ratios, and the combinations were measured at Mach numbers of 1·50 and 2·02 at a Reynolds number of 5·5 million (based on the body length) for angles of attack up to 5·5°. The total lift and pitching moment interference were determined and compared with theory. The agreement was found to be good.—(1.10.2.2).

Section characteristics of the N.A.C.A. 0006 *airfoil with leading-edge and trailing-edge flaps. B. J. Gambucci. N.A.C.A. T.N.* 3797. (*December* 1956).

Lift and pitching moment characteristics of an N.A.C.A. 0006 aerofoil are presented for various deflections of a 0·15-chord leading edge flap and a 0·30-chord plain trailing edge flap. Pressure distribution data are presented in tabular form. The data were obtained at a Mach number of 0·15 and a Reynolds number of 4,500,000.—(1.10.2.1).

An investigation at subsonic speeds of several modifications to the leading-edge region of the N.A.C.A. 64*A*010 *airfoil section designed to increase maximum lift. R. L. Maki and L. W. Hunton. N.A.C.A. T.N.* 3871. (*December* 1956).

Two-dimensional test data at both low and high subsonic speeds are presented for three aerofoil sections comprised of three related modifications to the leading edge region of the N.A.C.A. 64A010 section designed to improve maximum lift characteristics. Comparisons are made with both the N.A.C.A. 64A010 section and sections incorporating a distributed type of camber, the N.A.C.A. $a=1{\cdot}0$ mean line. —(1.10.2.1).

Helicopter Aerodynamics

See also—Aeroelasticity

Experimental investigation on the Langley helicopter test tower of compressibility effects on a rotor having N.A.C.A. 63_2-015 *airfoil sections. J. P. Shivers and P. J. Carpenter. N.A.C.A. T.N.* 3850. (*December* 1956).

An investigation has been conducted on the Langley helicopter test tower to determine experimentally the effects of compressibility on the hovering performance and the blade pitching moments of a helicopter rotor having N.A.C.A. 63_2-015 aerofoil sections. Data are presented for blade tip Mach numbers from 0·31 to 0·71. High tip-speed performance of the rotor having N.A.C.A. 63_2-015 aerofoil sections is compared with that of a rotor having N.A.C.A. 23015 aerofoil sections.—(1.11.3).

Testing and Instruments

Some notes on the flow durations occurring in hypersonic shock tubes. B. D. Henshall. C.P. 290. (1956).

The aerodynamic principles involved in the production of very strong shock waves and very high Mach number flows are summarised; subsequently the effects are considered of the deviations from perfect gas theory which occur when strong shock waves are generated. Some calculations of the flow durations occurring in hypersonic shock tubes are presented in tabular and graphical form.—(1.12.1.3).

The use of multiple diaphragms in shock tubes. B. D. Henshall. C.P. 291. (1956).

Calculations are presented which illustrate the advantages of various types of multiple-diaphragm shock tubes over the single-diaphragm convectional shock tube. Shock tubes having a discontinuous change of cross section at a diaphragm station or at any other position along the tube are also considered.—(1.12.1.3).

The development of an improved diffuser for a 3 *ft.* × 3 *ft. wind tunnel. J. B. Scott-Wilson and D. I. T. P. Llewelyn-Davies. C.P.* 308. (1956).

The significant results are summarised of diffuser development tests made in a 4 in. × 4 in. supersonic tunnel at Mach numbers from 1·4 to 2·0. The application of these results to the design of an improved first diffuser stage for the 3 ft. × 3 ft. supersonic tunnel is described.—(1.12.1.3).

High speed systems of wind tunnel data handling. J. Lukasiewicz et al. AGARD Report 17. (*February* 1956).

Force and pressure data handling systems which consist of commercially available components and with which it is possible to handle data at a rate of better than one point per second per channel and to record it simultaneously in analogue and in digital form, are described.—(1.12.1).

Measurement of the aerodynamic forces on oscillating aerofoils. W. G. Molyneux. AGARD Report 35. (*April* 1956).

Various techniques are considered for oscillatory force measurements in relation to their application to the measurement of the aerodynamic coefficients for a rectangular wing oscillating in modes of vertical translation and uniform pitch. The corrections which must be applied to such measurements are discussed also.—(1.12.4 × 1.6.3 × 2).

The use of rheo-electrical analogies in aerodynamics. L. C. Malavard. Agardograph 18. (*August* 1956).

After a review of the principle of the rheo-electric analogy method, the equipment and experimental techniques are described, followed by an examination of the aerodynamic applications.—(1.12.6).

AEROELASTICITY

See also Aerodynamics—Testing and Instruments

The flutter properties of a simple aero-isoclinic wing system. N. C. Lambourne and A. Chinneck. R. & M. 2869. (1956).

The flutter characteristics of a Hill aero-isoclinic wing are described. The aero-isoclinic property is dependent on the

change of incidence due to torsion of the wing being neutralised by that produced by wing bending. Flutter critical speeds and frequencies were measured over a range of the ratio of the bending and torsion frequencies; the results show that the aero-isoclinic condition is not sufficient to prevent flutter, and that the critical speed for flutter may be low. Forward mass-loading of the wing raises the critical speed. A method of flutter-speed calculation is given in which the aerodynamic terms are restricted to static derivatives only and no damping terms are present in the equations of motion. The solution yields a boundary between constant amplitude and growing oscillations. The method gives critical flutter speeds that agree well with the experiments.—(2).

A theoretical investigation of the factors affecting stalling flutter of compressor blades. A. D. S. Carter. C.P. 265. (1956).

The mechanisms of stalling flutter have been re-examined to establish, as far as is at present possible, the major parameters involved. On the basis of the hypothesis advanced, the factors governing the critical flutter velocity have been isolated. The variation of this velocity with respect to blade thickness has been deduced, and compared with test results.—(2).

Compressor cascade flutter tests. Part II. 40° camber blades, low and medium stagger cascades. D. A. Kilpatrick and J. Ritchie. C.P. 296. (1956).—(2).

Vibration and flutter flight testing. M. O. W. Wolfe. C.P. 310. (1956).

The techniques that have been or are being developed in the U.K. for flight vibration testing and flight flutter testing aircraft are reviewed. This includes a description of the instrumentation used for recording the vibrational response, and a comparative assessment of the various methods used for exciting the aircraft in flight flutter tests.—(2 × 13).

Flutter research at the Royal Aircraft Establishment, Farnborough. H. Templeton. AGARD Report 4. (*September* 1955).

The basic objective and the main activities of flutter research at the R.A.E. are outlined. Some examples of these activities are described.—(2 × 1.6.3 × 33.1.2).

Flutter prediction in practice. E. G. Broadbent. AGARD Report 44. (*April* 1956).

The resources available for flutter prediction, both experimental and theoretical, are summarised briefly. Specific flutter investigations are described for four actual recent flutter incidents, in all of which good agreement is eventually obtained between calculations and full scale experience. Conclusions for future guidance are drawn from all the examples, and a few points are given from a more general statistical survey of recent incidents.—(2).

Analytical determination of the natural coupled frequencies and mode shapes and the response to oscillating forcing functions of tandem helicopters. G. W. Brooks and J. C. Houbolt. N.A.C.A. T.N. 3849. (*December* 1956).

A method is presented for calculating the natural coupled frequencies and mode shapes of vertical vibrations of tandem helicopters; certain forced excitations are also considered. Degrees of freedom included are translation, pitching, and bending of the fuselage and the blades, and translation of the engine. Sample calculations show the modes for a given case, and indicate the changes in frequencies which result from variations in the uncoupled fuselage frequency and the Southwell coefficient. Frequency response functions of cockpit deflection for various applied oscillating forces are also given.—(2 × 1.11.0).

Flight measurements of the vibrations encountered by a tandem helicopter and a method for measuring the coupled response in flight. J. E. Yeates. N.A.C.A. T.N. 3852. (*December* 1956).

Flight-test and analysis methods for some selected helicopter vibration studies are discussed. The use of a mechanical shaker in flight to determine the structural response is reported. The analysis methods described are based on the determination of the power spectral density of the force and of the response due to the force through use of analogue frequency-analysis techniques. Results obtained by these methods are presented to show the coupled response of a helicopter in flight for two different blade configurations. In addition, natural-vibration measurements of some of the more important harmonics of rotor speed are presented for a range of speed and power conditions.—(2 × 1.11.0).

Measurement of the longitudinal moment of inertia of a flexible airplane. H. A. Cole and F. L. Bennion. N.A.C.A. T.N. 3870. (*November* 1956).

A method for measuring the longitudinal moment of inertia of a flexible aeroplane by ground oscillation tests is presented. The effects of flexibility on the fundamental frequency for various combinations of springs and knife edges are shown, and a method which minimises flexibility effects is developed. A description and results of tests which were conducted by this method are presented.—(2 × 33.3).

DESIGN AND CONTRUCTION

Recommendations on cockpit-visibility standards for transport-type aircraft. T. M. Edwards and W. D. Howell. C.A.A. T.D.R. 275. (*February* 1956).

The standards that are discussed in this report are recommended minimums for cockpit visual angles and were derived from technical information on the subject obtained through (1) an airline-pilot-questionnaire study, (2) a pilot-eye-movement study, (3) a collision-course study, and (4) development of a binocular camera for recording cockpit visual angles. These standards, when applied to initial aircraft-cockpit design, will improve the present safety level by affording the pilots better cockpit visibility, thus reducing the mid-air collision hazard.—(4.2.1).

AIRCRAFT OPERATION

Ground calibration of the V.O.R. C.A.A. T.D.R. 227. (*October* 1955).

A simple and accurate method of calibrating V.O.R. stations with a portable detector mounted on the edge of the counterpoise is described. A portable detector was designed specifically for this application, but those already in Federal Airways service may be used, after modifications. An accurate method of measuring phase was developed using existing equipment. The ground-calibration method provides a means for readily determining the calibration curve without interrupting the service of the station, and it can be used as an aid in routine and preventive maintenance. The counterpoise detector also can be used to measure the antenna radiation patterns during tune-up of the station.—(5.5).

Aircraft fire extinguishment. Part V. H. L. Hansberry. C.A.A. T.D.R. 260. (*February* 1956).

Provisional formulae based on data obtained during fire tests of XR60-1 and XB-45 aircraft power plants are derived for the design of adequate high-rate-discharge fire-extinguishing systems in potential fire zones. These formulae apply to zones through which there is a high air flow and in which the internal surfaces are smooth, and to zones through which there is very little or no air flow and the internal surfaces are rough to any degree.—(5.3).

HYDRODYNAMICS

Towing tank tests to determine the water drag of the hull of a jet propelled flying boat fighter (Spec. E.6/44) and comparison with full scale measurements. R. V. Gigg et al. C.P. 284. (1956).—(17.2).

MATERIALS

Compressive stress-strain properties of 2024-T3 *aluminum-alloy sheet at elevated temperatures. E. E. Mathauser. N.A.C.A. T.N.* 3853. (*November* 1956).

Results are presented for temperatures up to 700°F. and exposure times from 0·1 to 100 hours. Significant design data obtained from the stress-strain curves (yield stress, Young's modulus, secant and tangent moduli and two stresses useful for determining the maximum compressive strength of plates) are presented in graphical and tabular form. A rate-process relationship is used to determine exposure time which produces a maximum yield stress for a given temperature, and a time-parameter is used to present the yield stresses as a single master curve.—(21.2.2).

MATHEMATICS

The determination of matrix eigenvalues by the Hollerith computer. J. Guest. A.R.L. Note S.M. 233. (*August* 1956).

A method is proposed for the evaluation of matrix eigenvalues by Hollerith equipment. Strictly speaking a more general programme was devised to perform the general matrix multiplication AB (where A has r rows and s columns, and B has s rows and p columns). For the more special case, when seeking eigenvalues by matrix iteration B is always a column vector *i.e.* $p=1$. It was found that most of the simpler dominant roots can be found speedily with a considerable saving in time as compared with a desk computer.—(22).

METEOROLOGY

Turbulence encountered by Viking aircraft over Europe. J. R. Heath-Smith. C.P. 311. (1957).

Accelerations in turbulence were recorded on Viking aircraft for 117,000 miles of flying over European routes during three years. The records show that the number of gusts decreases from sea level to 8,000 ft. There is some evidence below 5,000 ft. that turbulence is greatest in Spring and least in Autumn. Average gust frequencies during climb and descent were twice those during cruise below 8,000 ft. and this is attributed to the pilot's discretion in the choice of cruising altitude.—(24).

Experimental droplet impingement on several two-dimensional airfoils with thickness ratios of 6 to 16 per cent. T. F. Gelder et al. N.A.C.A. T.N. 3839. (*December* 1956).

The rate and area of cloud droplet impingement on several two-dimensional swept and unswept aerofoils were obtained experimentally in the N.A.C.A. Lewis icing tunnel with a dye-tracer technique. Aerofoil thickness ratios of 6 to 16 per cent, angles of attack from 0° to 12°, and chord sizes from 13 in. to 96 in. were included in the study. The results are presented in the form of dimensionless impingement parameters in order to cover a wide range of flight and atmospheric conditions.—(24).

POWER PLANTS

See also AERODYNAMICS—COMPRESSIBLE FLOW

The influence of engine speed upon pre-ignition. E. M. Goodger. CoA Note 51. (*September* 1956).—(27.2.2).

FATIGUE

Estimation of fatigue life of structures from observed damage. D. G. Ford and J. L. Kepert. A.R.L. Note S.M. 232. (*July* 1956).

In estimating the residual life of an unbroken fatigue specimen, a procedure based on comparison of crack propagation rates has been found to give reliable results. A statistical method using maximum likelihood estimators showed reasonable agreement. The desirability of using this method as a check on the estimates has been discussed.—(31.2.1.2 × 33.2.3).

Research on cumulative damage in fatigue of riveted aluminum alloy joints. J. Schijve and F. A. Jacobs. N.L.L. Report M. 1999. (*January* 1956).

Two-step tests and interval tests were performed on 24 *S-T* Alclad riveted lap joints to study the cumulation of fatigue damage in this type of joint and to verify the linear cumulative damage rule. Available data on light alloy specimens are reviewed and compared with the results of the present investigation. Some proposed cumulative damage rules are discussed with respect to the experimental results and general accepted features of the fatigue phenomenon. Some remarks are made on the life estimation of structures under service loading. Proposals for further investigation are made.—(31.2.3.2.2.2 × 33.2.4.13.10).

STRUCTURES

LOADS—*see* AEROELASTICITY

THEORY AND ANALYSIS—*see also* FATIGUE

On the theory of thin shallow shells. A. A. Nazarov. N.A.C.A. T.M. 1426. (*December* 1956).

The equations for a shallow shell are set up in "almost Cartesian coordinates" using a tensor approach. These equations are then reduced to two simultaneous fourth-order equations for the deflection and a stress function analogous to Airy's.—(33.2.4.11).

Failure characteristics of pressurized stiffened cylinders. R. W. Peters and N. F. Dow. N.A.C.A. T.N. 3851. (*December* 1956).

Stiffened cylinders of 2024 and 7075 aluminium alloys, representative of fuselage construction, were tested under internal pressure and cyclic torsion. Fatigue cracks which developed in the skin resulted in both gradual and explosive types of failure. The types of failure depended upon the hoop stress and the structural configuration, and particularly upon the ratio of area in rings to associated skin area. The tests indicated that the 7075 alloy is somewhat more prone to the explosive type of failure.—(33.2.3.3).

TESTING—*see* AEROELASTICITY

THERMODYNAMICS

See also AERODYNAMICS—THERMO-AERODYNAMICS

Calcul numérique, calcul physique. Application a la thermocinétique. P. Vernotte. Pubs. Sc. et Tech. No. 319. (1956).

Exposé des aspects les plus caractéristiques des phénomènes thermocinétiques. Méthods de grande efficacité pour résoudre les équations et sommer les séries très lentes, auxquelles on est conduit. Méthodes de dépouillement des mésures.—(34).

Effect of pressure on the spontaneous ignition temperature of liquid fuels. C. O'Neal. N.A.C.A. T.N. 3829. (*October* 1956).

Spontaneous ignition temperatures were measured in air for *n*-heptane, iso-octane, benzene, and JP-4 and JP-5 aviation fuels in the pressure range of 1 to 9 atmospheres. A solid stream (no spray) of fuel was injected into a 125-cc Erlenmeyer flask enclosed in a bomb. Fuel charges were varied so that the lowest temperature at which spontaneous ignition occurs was obtained. Time lags before ignition were measured.—(34.1.1).

Growth of disturbances in a flame-generated shear region. P. L. Blackshear. N.A.C.A. T.N. 3830. (*November* 1956).

This paper contains a stability analysis of the flow field that arises when a flame is anchored in a duct and an experimental examination of the growth of disturbances imposed on an anchored V-flame in a duct.—(34.1.1).

Stability limits and burning velocities of laminar hydrogen-air flames at reduced pressure. B. Fine. N.A.C.A. T.N. 3833. (*November* 1956).

Laminar burning velocity was measured at pressures of 1 atm. and below and critical boundary velocity gradient for flashback below 1 atm. over a range of compositions for hydrogen-air burner flames. Both quanities were correlated with pressure, the pressure dependence being independent of composition between equivalence ratios of about 1 and 2. A more general correlation involving quenching distance conformed to a simple quenching model.—(34.1.2).

A relation between burning velocity and quenching distance. A. E. Potter and A. L. Berlad. N.A.C.A. T.N. 3882. (*November* 1956).

The product of burning velocity and quenching distance is proportional to a term which has the character of a thermal diffusivity and a term which increases with the activation energy of the flame reaction. The quotient of burning velocity and quenching distance is proportional to the average flame reaction rate and to terms which are mildly dependent on the flame reaction activation energy and the transport properties.—(34.1.1).